

Research Article

Disruptive Product Innovations: A New Definition and Seven Theses

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Abstract

The importance of disruptive product innovations is undisputed. However, the understanding of what constitutes a disruptive innovation varies widely in academic discourse. Therefore, this paper begins with a new definition of disruptive product innovation based on the design of the product innovation and its subsequent adoption by competitors. It then presents the results of an ongoing research project that uses a qualitative case study approach to analyze product innovations from the last fifty years that meet this definition. Both the design and the development process of these product innovations have been examined in detail. In particular, the effective principles and structures, geometric layouts and operating concepts used in the product innovations were analyzed, as were the differences to previous products. In addition, changes in the social and technological environment that led to the innovations were examined, as well as the role of new enabling technologies, in particular new materials and production processes. The common patterns across cases identified through the analysis were condensed into seven theses, which are presented in this article, each of them illustrated by using the example of the first iPhone. Said theses reflect the central research findings on (1) "Key usability contradictions as starting points", (2) "User-centeredness", (3) "Co-evolution of problem and solution space", (4) "Technical fixations that create cognitive gravitation", (5) "Facilitation through new technologies and reciprocal enablers", (6) "Higher degree of ideality" and (7) "Shifting tasks in the overarching human-product interaction system to the product". Finally, starting points for further research are formulated.

Keywords

Innovation, Product Design, Disruptive Innovation, Product Innovation, iPhone, Design Thinking

1. Introduction

Innovations are of central importance for companies and competition [1, 2]. The product development processes that led to these innovations have therefore been studied extensively for decades [3, 4]. In particular, the development of so-called "disruptive innovations" is recognized as a key success factor for many leading companies since they have

the potential to fundamentally change entire industries and business models [5–7]. However, the understanding of "disruptive innovations" and, derived from that, "disruptive product innovations", differs significantly depending on academic perspective and practical context [8].

The central research questions of this paper can be formu-

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Received: 5 February 2024; **Accepted:** 21 February 2024; **Published:** 7 March 2024



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lated as follows: (1) how can disruptive product innovations be defined and (2) what characterizes their development process. Therefore, the aim of this paper is (1) to provide a conceptual clarification of the term disruptive product innovation providing a new definition and (2) to identify common patterns in the innovation processes that fostered the development of products that fit this definition. This paper focuses on physical product innovations launched in the last fifty years; service, process and business model innovations are not part of our analysis.

In simple terms, a disruptive product innovation, as understood in this paper, means that there is a *"world before the new product and one after"*, implying after its introduction further products developed and launched in this respective product category are based on the same effective principles and structures as well as utilizing the same operating concepts.

This paper is structured as follows: Section 2 analyses existing definitions of disruptive innovations and describes their limitations. It also presents a new definition of disruptive product innovations, which serves as the basis for this paper. Section 3 describes the methodology of the empirical analysis of several cases that fit this paper's definition of disruptive product innovations. The common patterns across cases identified in this analysis are condensed into seven theses, which are presented in section 4. Each of these theses is illustrated using the specific example of the first iPhone, as it is a particularly striking example of a disruptive product according to this paper's definition, being the *"prime father"* of all smartphones in today's sense [9]. The paper concludes with a summary and outlook on the need for further research in section 5.

2. Defining Disruptive Product Innovations

The term *"disruptive innovation"* was originally coined by Christensen, C. M. [6]. It refers to developing technologies, on which new processes and products might be based, that are initially inferior to established technologies measured by traditional criteria but offer higher *"ancillary performance"* [10] by focusing on previously neglected attributes. Said technologies have the potential to improve steadily as they evolve, eventually surpassing and substituting established technologies as well as displacing established competitors [11, 12]. Thus, disruptive innovations are the result of fulfilling latent customer needs that existing offerings fail to fulfil [13]. Utterback, J. M. and Acee, H. J. [10] expand the view on disruptive technologies: According to them, a disruptive innovation must not necessarily be an *"attack from below"* but could also involve higher performance as well as a higher price and initially being introduced to the most demanding market segments before moving to the mass market. However, they still see disruptive innovation as a process that takes place over a longer period, sometimes several years. Although

the theory of disruptive innovation has been advanced by many different researchers, such as e.g. Assink, M. [14] and Leifer, R. et al. [5], some still consider it to be in its infancy due to a lack of understanding and empirical data [15]. To enable an understanding which innovations are to be classified as disruptive, Danneels, E. [16] and Nagy, D. et al. [17] emphasize the need of an improved definition of disruptive product innovations.

The limitations of the existing definitions of disruptive innovations and, derived from this, disruptive product innovations, are, that they (1) focus primarily on the market and the customers and (2) understand disruptive innovation as a process over time. They do not capture an aspect of disruptive product innovations that we believe is of utmost importance: the introduction of new effective principles, effective structures and geometric layouts leading to superior usability right from the launch of the new product and therefore being subsequently adopted by all competitors in the respective product category. The limitations of the existing definitions can be illustrated using the example of the first iPhone: although it completely redefined the smartphone category by creating *"the new dominant design for mobile internet devices"* [18], the iPhone is not classified as a disruptive innovation according to the existing definitions.

Therefore, we define the term *"disruptive product innovation"* as follows:

"A disruptive product innovation is a product that creates a dominant design in its respective product category by introducing new solution-determining effective principles, effective structures and geometric layouts, which are later adopted by all competitors."

Hereby, effective principles are determined by the physical effect utilized by the function carriers and their geometric and material characteristics [19]. The effective structure is defined by the combination of effective principles to fulfil the solution-determining main functions of the product. It determines the principle solution respectively the conceptual design of the product [19]. The geometric layout refers to the embodiment design (partial and overall design) of the product. The adoption of the new design by competitors, which is central to our definition, is typically driven by its superior usability, often characterized by a new operating concept (Figure 4). Usability is thereby determined by the functionality (*"effectivity"*) and the performance (*"efficiency"*) of a product. The core of our definition is, that the introduction of the disruptive product innovation completely redefines the respective product category, or even creates a new one, by changing respectively establishing the way how products of this category are designed, manufactured, and used. Thus, the introduction of a disruptive product innovation marks a *"caesura"*, virtually dividing the time into an *"era before"* and an *"era after"*.

3. Materials and Methods

A qualitative case study approach was used to investigate various product innovation cases. In the first step, the sample for the empirical analysis was determined. Based on literature reviews and discussions with academic colleagues, several disruptive product innovations that fit our definition presented in section 2 were identified. In doing so, we have focused exclusively on physical products that have been launched over the course of the last fifty years. In the second step, the selected cases were investigated with respect to the following aspects:

1. the changes in the social and technological environment prior to the introduction of the disruptive product innovation,
2. the effective principles, effective structures, geometric layouts and operating concepts utilized in the disruptive product innovations and their differences from previous

products,

3. new enabling technologies, especially new materials and production processes,
4. the development process and design methodologies employed.

This was done by reviewing corporate and popular scientific publications and patents, as well as interviews and presentations by company representatives. The entire selection process and analysis outlined above was conducted independently by two of our senior researchers specializing in industrial product development. If differences in their assessments arose, their results were consolidated with yet another expert's assistance.

In a final step, the common patterns identified across the cases were condensed into seven theses on disruptive product innovations, which are presented in the next section. Since this work is part of a larger, still ongoing research project, the findings obtained so far are presented using only a single case: the case of the first iPhone (Figure 1).

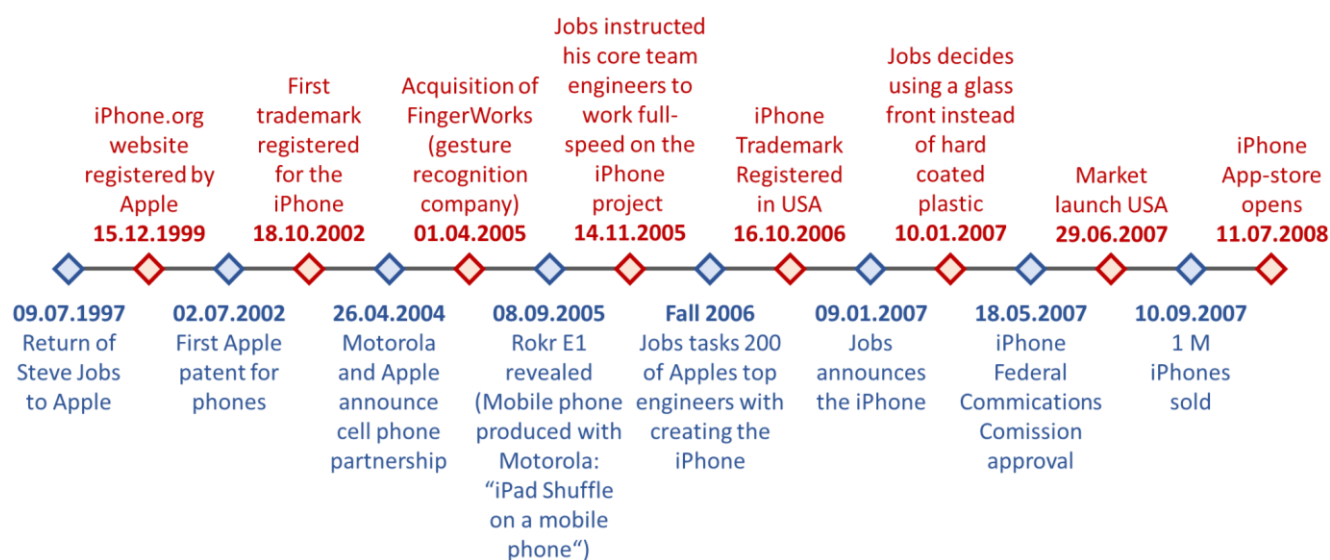


Figure 1. Timeline of the iPhone's innovation process.

4. Results: Seven Theses on Disruptive Product Innovations

The seven theses, which reflect the common patterns identified in the different innovation cases, are presented below. Each of these theses is illustrated using the specific example of the first iPhone.

4.1. Thesis 1

Thesis 1: Key usability contradictions represent the starting points for disruptive product innovations.

The starting point for disruptive product innovations, as

understood in this paper, are key usability contradictions that are not adequately resolved by existing products. These key contradictions in usability arise from changes in user needs, which in turn arise from changes in the social and technological environment. In contrast to TRIZ (TRIZ: Theory of Inventive Problem Solving), in which technical contradictions are the starting point for innovations, our analysis has shown that the starting point for disruptive product innovations were key contradictions at the level of human-product interaction, which we call "key usability contradictions".

Illustration of thesis 1 using the example of the iPhone:

At the time the first iPhone was introduced, Internet use was already widespread in both professional and private contexts. People were familiar with connecting to the Internet using their desktop PC or their laptop. Likewise, the use of

mobile phones to make phone calls and write text messages was widespread. Mobile networks were continuously evolving in terms of both area coverage and the possible bandwidths for data transmission. As people became familiar with the benefits of the stationary Internet, their desire to be able to use the Internet on mobile devices grew continuously [18]. This newly emerged customer need, however, gave rise to a central contradiction in usability: On the one hand, a mobile Internet device had to have a size and weight that made it easy to carry, comparable to that of a mobile phone at the time. On

the other hand, to allow for a practicable use of the Internet, such a device had to have (1) a display that was as large as possible and (2) a flexible input device that was easy to use and, above all, easily adaptable to different applications.

The smartphones already existing at the time of the first iPhone's introduction, such as e.g. Motorola's Moto Q8, RIM's Blackberry 8820, palmOne's Treo 650 and the Nokia E62, were unable to resolve this key usability contradiction because they were all based on the traditional display-plus-keypad concept (Figure 2).



Figure 2. Existing Smartphones at the time of the first iPhone's presentation.

In this concept, the permanently installed keypad competes with the display for the available installation space. In addition, keypads and buttons neither enable easy operation of Internet applications nor flexible adaptation to different applications.

The iPhone solved this key contradiction in terms of usability by introducing the multitouch display omitting permanently installed keys for entering numbers and letters or operating applications. The keypad was only shown on the display when it was actually needed to enter alphanumeric information. When alphanumeric input was not required, almost the entire front of the iPhone could be used for display. The multitouch display was very intuitive to use and facilitated an easy adaption of the user interface to different applications.

4.2. Thesis 2

Thesis 2: User-centeredness is the prerequisite for identifying key usability contradictions.

Since usability key contradictions result from changes in user needs, identifying them requires a high level of empathy

with potential users. This empathy can only be developed if the entire innovation and product development process is guided by strict user-centeredness.

Illustration of thesis 2 using the example of the iPhone:

Steve Jobs, the key person in the innovation process of the first iPhone, has always promoted a strict focus on the user experience for each product developed under his responsibility [20]. He believed that technology and ideas alone were insufficient to create a successful product, but that it was crucial to place user experience as a top priority in the development process [21]. This is clearly reflected by one of his famous quotes: "You've got to start with the customer experience and work backwards to the technology. You can't start with the technology and try to figure out where can I sell it" [22]. Consequently, when presenting the first iPhone, Steve Jobs showed a slide that illustrated the strategic positioning of the iPhone compared to existing competitive products based on two parameters: usability and smartness, highlighting the paramount importance of usability in the development of the iPhone (Figure 2).

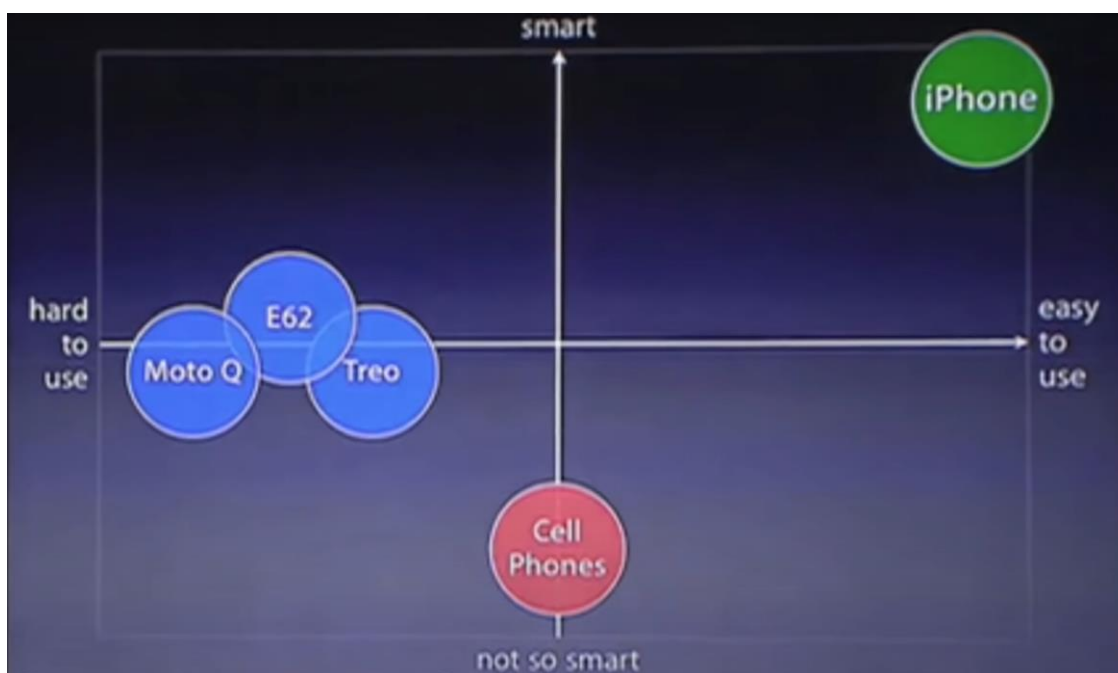


Figure 3. Product positioning matrix of Steve Jobs' presentation of the first iPhone.

According to Steve Jobs, a coherent product vision must also include how products align with people's lifestyles and their potential interactions with them [21]. Therefore, every new product presentation by Apple is accompanied by a clear and easy-to-understand user story that demonstrates the benefits of the product to potential users and effectively conveys how it fits into their lives.

4.3. Thesis 3

Thesis 3: Resolving key usability contradictions requires a co-evolution of problem and solution space in the development process.

Disruptive innovations require a fundamentally new understanding of the underlying problem and the user needs associated with it. Since problem space and solution space are not separate spheres, but two sides of the same coin, a comprehensive and deep understanding of the problem often only emerges during solution development. Disruptive innovations therefore usually result from a concomitant iterative development of problem understanding and solution [23, 24]. This "coevolution of problem and solution space" [25], as is characteristic of e.g. design thinking, is guided by user interaction tests in which prototypes embody certain aspects of the evolving product to understand user needs and derive design requirements [23].

Illustration of thesis 3 using the example of the iPhone:

Apple is known for having adopted the core principles of design thinking early in its innovation process. The company already utilized it when developing the first Macintosh computer [26]. Borah, H. K. [27] describes how Apple used design thinking in the development of the first iPhone and

considers the iPhone to be "a testament to how design thinking, with its focus on empathy, creativity, and user-centricity, can lead to groundbreaking products that reshape industries and improve the lives of millions".

The concomitant iterative development of problem understanding and solution is best reflected by the following quote from Steve Jobs:

"When you start looking at a problem and it seems really simple with all these simple solutions, you don't really understand the complexity of the problem. And your solutions are way too oversimplified, and they don't work. Then you get into the problem and you see it's really complicated. And you come up with all these convoluted solutions. That's sort of the middle, and that's where most people stop, and the solutions tend to work for a while. But the really great person will keep on going and find the key, underlying principle of the problem. And come up with a beautiful elegant solution that works." [28]

The following two quotes from Larry Tesler, who came to Apple in 1980 and, among other things, invented the copy-and-paste function, also show that the development process at Apple is characterized by an iterative, prototype-based approach, which is accompanied by intensive usability testing:

"What I realized [is] the best way to design software [at Apple] is with the customer, which is now called participatory design. [...] I watched how they used it and saw when they got confused. [...] That was my first experience with what we call usability tests today." [29]

"In the user interface design, it was a lot of trial and error. We tried different things and found out what did and didn't work. A lot of it was empirically driven. I kept bringing new stuff in and saying, 'What about this?' and [we would] set up tests so that different people could try it." [29]

Steve Jobs was also known for relying on prototypes when making design decisions:

"Jobs made decisions based on touching and playing with the prototype, not by evaluating data and decks and the financial analyses of a PowerPoint presentation." [20].

4.4. Thesis 4

Thesis 4: Technical fixations create cognitive gravitation.

The analysis of different cases has shown that disruptive product innovations often came from companies that had never produced a product of the respective category before. We see this as an indication that existing technical fixations, such as proven technical functions carriers as well as existing production facilities and supply chains, create what we call *"cognitive gravitation"* in a company, meaning they induce cognitive solution fixations, especially in developers and designers of these companies, thus acting as innovation barriers.

Illustration of thesis 4 using the example of the iPhone:

Although Apple had produced iPods and various types of computers before introducing the first iPhone, the company had never produced a mobile phone. This distinguishes Apple from all its competitors. All other smartphones available at the time the first iPhone was unveiled, were made by companies already being established in the business of conventional mobile phones respectively communicators. Their technological know-how, manifested in their existing products, production facilities and supply chains, led them to stick to the traditional keypad-plus-display concept when developing their first smartphones. They simply developed their existing solutions, which had proven successful, further incrementally by adding new features, the most important of which was Internet capability. Since Apple was new to the mobile phone business, the company had to start from scratch. This circumstance proved to be an advantage, as it allowed Apple to explore both the problem and solution space without being constrained by underlying cognitive solution fixations.

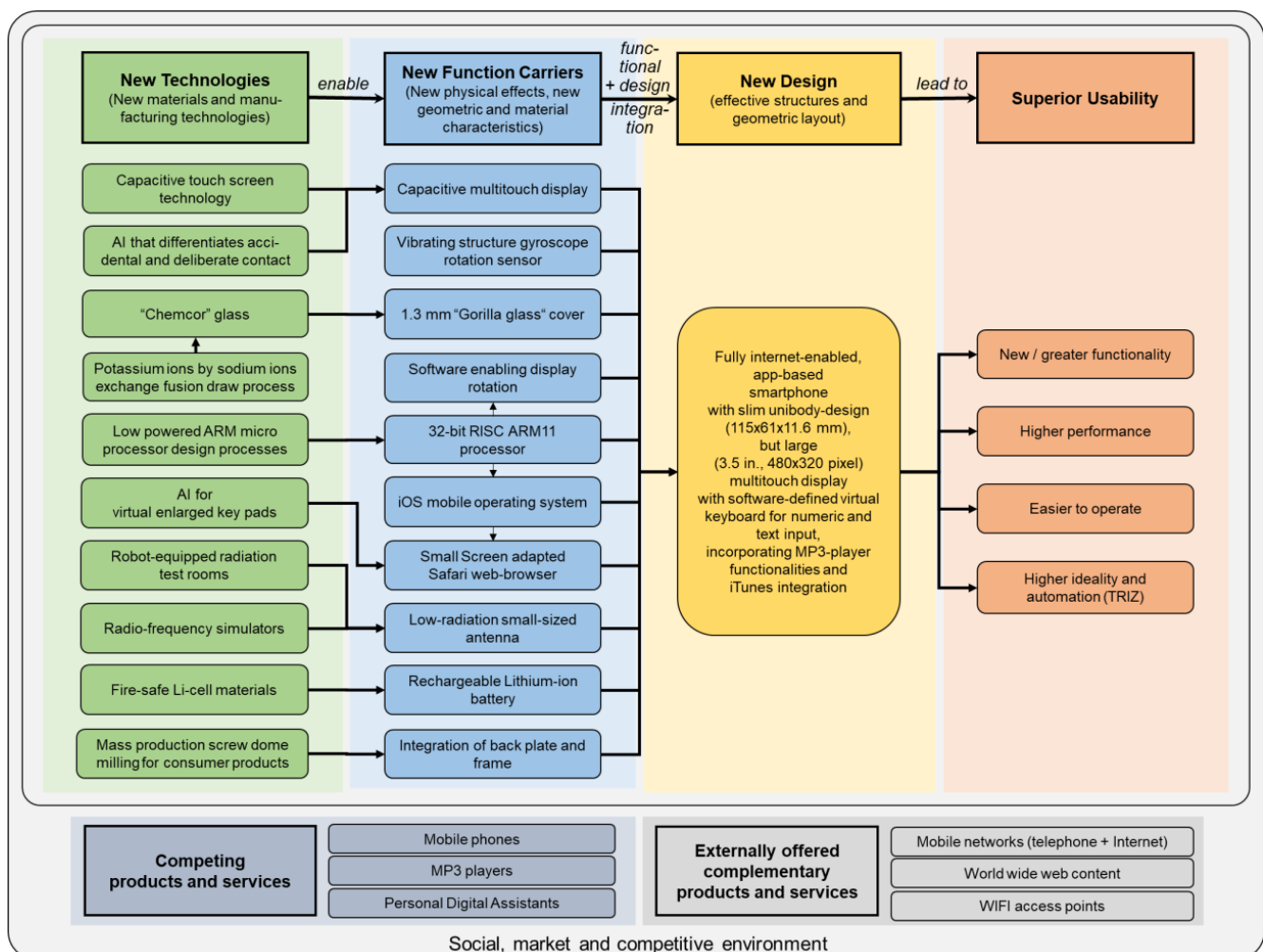


Figure 4. The innovation cascade for the iPhone.

4.5. Thesis 5

Thesis 5: Disruptive innovations are facilitated by new technologies and reciprocal enablers.

Our analysis has shown that the resolution of key usability contradictions as described in section 4.1 usually involves the implementation of new technologies. Hereby, new materials and production processes facilitate the development of new function carriers. The effective principle of said function carriers can include new physical effects as well as new geometric and material characteristics. We also found that disruptive product innovations often involve multiple innovations in the three domains (1) new technologies (materials and production processes), (2) new effective principles, (3) design (effective structure and embodiment design). The synergistic interaction of the individual innovations in the respective domains only enables the disruptive innovation's quantum leap in terms of functionality and performance. We call this phenomenon the concept of "reciprocal enablers", which can be visualized in an "innovation cascade" (Figure 4).

Illustration of thesis 5 using the example of the iPhone:

The most striking innovation of the first iPhone is without a doubt the multitouch display patented by Apple. Although preceded by some other inventions that paved the way, "Apple undoubtedly brought both capacitive touchscreens and multitouch to the forefront of the industry" [30]. The capacitive multitouch display is the central new technology on which the whole design and operating concept of the iPhone is based. According to renowned computer scientist Bill Buxton, "The iPhone made a quantum leap in terms of being the first really successful digital device that had, for all intents and purposes, an analog interface" [30]. The invention of the multitouch display involved new materials, such as e.g. "Gorilla Glas", and production processes and is accompanied by the use of new proximity and acceleration sensors that are closely connected to the function of the multitouch display. Another enabling technology was the ARM11 (ARM: Advanced Reduced Instruction Set Computer Machines) microprocessor. The high multimedia processing performance and low power consumption of the ARM11 chip enabled the operation of a multitouch display the size of the first iPhone display and provided the computing power required for its functionality.

4.6. Thesis 6

Thesis 6: Disruptive innovations exhibit a higher degree of ideality in the sense of TRIZ than previous competitive products.

We have found that disruptive product innovations always exhibit a higher degree of ideality in the sense of TRIZ than previously existing competitive products. Ideality in the sense of TRIZ can generally be defined as the ratio of useful functions to effort and unwanted or even harmful functions [31]. For physical products, ideality is closely linked to the product's size and weight: Provided that the product's functionality remains the same, reducing its size and weight increases its

ideality. In order to reduce the size and weight of a product, the principle of functional integration has to be utilized in its design to avoid physical redundancies.

Illustration of thesis 6 using the example of the iPhone:



Figure 5. Functional integration realized by the iPhone's multitouch display.

The first iPhone already implemented a functional integration of three previously existing products at the overall function level. When presenting the first iPhone, Steve Jobs emphasized that it combined the functionality of (1) an iPod, (2) a mobile phone, and (3) an Internet device. At the level of the main function carriers, the most important functional integration was realized with the multitouch display, as it integrates the display and input function, which in the previously existing smartphones were fulfilled by two different components, i.e. display and keypad (Figure 5). This functional integration not only made the revolutionary operating concept of the first iPhone possible but also reduced its size and weight compared to a smartphone based on the previous display-plus-keypad concept with a display of the same size.

4.7. Thesis 7

Thesis 7: Disruptive product innovations involve a shift of tasks in the overarching human-product interaction system to the product.

The analysis has shown that disruptive product innovations are accompanied by a shift of tasks in the overarching human-product interaction system from the user to the product, i.e. the user is relieved of tasks compared to the use of previous competitive products. This phenomenon corresponds with the evolution pattern of increased automation from TRIZ, the technical realization of which is often achieved by integrating different subsystems into a higher-level system. This design principle corresponds yet with another evolution pattern from TRIZ that states that the complexity of a system first increases before it finally becomes simplified.

Illustration of thesis 7 using the example of the iPhone:

The integration of Internet capability into the smartphones

that existed before the first iPhone required additional control buttons, for example, to move a pointer in Internet applications before making a selection. Compared to conventional mobile phones, this led to an increased complexity of the technical system and made operation more difficult for the user (Figure 3). In contrast, the multitouch display of the first iPhone, which integrated the previous subsystems "keypad" and "display" into a higher-level system, significantly reduced the number of input operations for the user. For example, making a selection no longer required prior positioning of a pointer using a trackball or control buttons. Other use cases that required multiple control button inputs on previous smartphones, such as enlarging a specific image section, could also be carried out with the first iPhone using simple gesture control. In addition, the proximity sensor and the acceleration sensor allowed for the automatic deactivation of the display and automatic alignment of photos from portrait to landscape respectively.

5. Conclusion and Outlook

This paper presents the results of an ongoing research project. First, a new definition of disruptive product innovation is developed. This definition is based on the creation of a new design with superior usability that is adopted by all competitors and becomes the dominant design in its respective product category. The design and the development process of several product innovations over the last fifty years that could be classified as disruptive according to this definition were analyzed in detail. In addition, changes in the social and technological environment leading up to the innovation were also analyzed. Through this in-depth study of different product innovation cases, common patterns across the cases were identified and condensed into seven theses, which are presented in this paper. Each of these theses is illustrated using the specific example of the first iPhone.

By analyzing additional cases of disruptive product innovations, further research should validate the findings of our study on a broader empirical basis. Furthermore, certain aspects described in the theses presented should be investigated in more detail. This applies in particular to the interaction between different reciprocal enablers in the innovation cascade and the effect of cognitive gravitation. Future research should also investigate the influence of company size and organization as well as the importance of key people in the development of disruptive product innovations.

Abbreviations

ARM: Advanced Reduced Instruction Set Computer Machines

TRIZ: Theory of Inventive Problem Solving

Conflicts of Interest

The authors declare no conflicts of interest.

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