DOES VIRTUAL PROTOTYPING KILL THE POTENTIAL FOR DISRUPTIVE INNOVATION?

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A critical element of a corporate entrepreneur's opportunity evaluation process will involve the attempt to understand customer requirements in order to calculate commercial demand. Traditional opportunity evaluation processes are less effective in the face of potentially disruptive innovations, as customers lack understanding and are unable to articulate their needs. Physical prototyping emerged as a method to test novel concepts in both familiar and unfamiliar markets; today, virtual prototyping is fast growing into this role in favour of the slower and more expensive production of physical models. Yet, anecdotal evidence suggests that virtual prototyping systems compromise the evaluation of opportunities with disruptive potential. We address the need for empirical analysis with an experimental design in which we evaluate customer reactions to a potentially disruptive innovation in the mobile telecommunications sector. Our findings contribute evidence to suggest virtual prototypes are significantly less effective than physical prototypes at eliciting a deep customer understanding of potentially disruptive innovations. This work has repercussions for theory and for corporate entrepreneurs tasked with driving the disruptive potential of their firms.[1]

INTRODUCTION

There is a significant stream of research into corporate entrepreneurship (Burgelman, 1983; Zahra, 1993) which aims to deliver an improved process based understanding of the recognition and development of new opportunities and the birth of new ventures (Burgelman, 1983; Zahra, 1993; Gans and Stern, 2003). Entrepreneurial opportunities can be defined as "situations in which new goods, services, raw materials, markets and organising methods can be introduced through the formation of new means, ends, or means-ends relationships" (Eckhardt and Shane, 2003, p 336). The ability to recognise opportunities is not evenly distributed across firms and managers because different people, in different contexts, have different conceptualisations about the relative value of resources when they are converted from inputs into outputs (Kirzner, 1979; Shane and Venkataraman, 2000). Hence, scholars have placed a significant emphasis on the actions and decision-making approaches underpinning the opportunity recognition process (Leifer, et al, 2000; Rice et al., 2001; O'Connor and Rice, 2001; Ardichvili, Cardozo and Ray, 2003; Davidsson, 2003; Baron, 2006; Gordon, 2007). A better understanding of the opportunity recognition process, and the individual and firm differences that exist, can be derived by delineating the process into three elements: opportunity identification, opportunity development and opportunity evaluation (Ardichvili et al., 2003).

The process of opportunity identification begins with an initial vision, or business idea, which is developed into an elaborated vision, or business opportunity (Long and McMullan, 1984). In a corporate context, it is the business ideas that are evaluated by managers as desirable and feasible which are developed into business opportunities (Burgelman, 1983; Burgelman, Maidique and Wheelwright, 1996). The process of opportunity identification builds upon an initial idea and drives it into the next process of opportunity development, where it is cultivated into an emerging entrepreneurial venture. Hence, opportunity development is a process by which managers commit and expend their firm's resources to evaluate new business opportunities and to develop those that are desirable and feasible into new business ventures (Baron, 2006; Leifer, et al, 2000; Rice et al., 2001; O'Connor and Rice, 2001). The process of *opportunity evaluation* is therefore a critical element of both the opportunity identification and opportunity development processes and is also ultimately used to complete the opportunity recognition process when corporate entrepreneurs decided to formally engage organisational support to pursue specific new business ventures (Burgelman, 1983).

The opportunity evaluation process is complicated by corporate entrepreneur's pursuit of two broad types of opportunities (Tushman and O'Reilly, 1996). Most commonly, businesses need opportunities that offer sustaining innovations - minor or major improvements and variations to their established value propositions. However, continued variations on a theme, whether incremental or radical, eventually loose their ability to deliver significant returns and success (Foster, 1986a, 1986b; Tushman and O'Reilly, 1996). Hence, managers may be required to identify opportunities that challenge established trajectories of improvement by establishing a completely different trajectory. The motivation for this discontinuous act is that it may re-shape the existing terms of economic engagement in established industries and provide the disruptive business with the opportunity to create new wealth and substantial long-term value (Abernathy and Clark, 1985; Carrol, 1985; Christensen, 1997; Timmons, 1999; Walsh and Kirchhoff, 2002) – we refer to these as disruptive technologies (Christensen, 1997) and disruptive innovations (Christensen and Overdorf, 2000; Christensen and Raynor, 2003)[2].

Traditional approaches to evaluating sustaining innovations, by capturing the 'voice of the customer', can undermine the pursuit of disruptive innovation as most customers' frame of reference is limited by past experience (Christensen, 1997; Leonard and Rayport, 1997; Ulwick, 2002). Consequently, trying to obtain early market forecasts and customer based evaluations for potentially disruptive innovations have proven to be a significant management challenge (Christensen, 1997; Cooper, Edgett and Kleinschmidt, 2001). One of the popular methods employed by corporate entrepreneurs to surmount the challenge posed by the evaluation of non-sustaining innovation is the testing of physically prototyped 'new concept' models in both familiar and unfamiliar markets (Boehm, Gray and Seewaldt, 1984; Cooper et al, 2001; Kelley and Littman, 2001).

Today's prototyping methods can be broadly delineated into physical and virtual approaches. Recent analyses reveal that the continual drive for cost and time efficiencies underpins the distinct growth in the use of virtual prototyping within activities that would have previously been the domain of physical prototyping (Gordon and Bieman, 1994; Tidd Bessant and Pavitt, 1997; Kelley and Littman, 2001). While there are obvious benefits of using virtual prototyping to help evaluate emerging opportunities, there remains a lack of compelling empirical data to demonstrate the complete effectiveness of virtual prototyping approaches. In particular, there is an apparent absence of published empirical comparisons of physical and virtual systems in terms of their effectiveness for facilitating the opportunity evaluation of potentially disruptive innovations. As we only find anecdotal comparisons of physical and virtual prototyping, which suggest that virtual prototyping may be counter-productive to the pursuit of non-sustaining opportunities (Allen et al., 1999; Kelley and Littman, 2001), we highlight the necessity, along with our intention, to address this gap in the literature. Hence, the aim of this paper is to offer an improved understanding of how the corporate entrepreneur can deliver customer based evaluations of a potentially disruptive opportunity before determining whether or not organisational support for product[3] development should commence. In particular we seek to answer the question: are virtual prototyping systems as effective as physical prototyping systems in supporting customer based opportunity evaluations and eliciting customer requirements during the early development of potentially disruptive innovations?

The paper is delivered in four parts. Part one offers a theoretical and industrial background. We discuss the difficulties of achieving the general objectives of opportunity evaluation in the face of potentially disruptive opportunities; then we discuss how these objectives can be facilitated with the use of prototyping. Part two of this paper presents an overview of our experimental approach. We compared the effectiveness of a virtual and physical prototyping system for obtaining insights into the customer requirements of a potentially disruptive innovation in the telecoms sector; we also probed a sustaining innovation as a control variable. In part three, we present results which illustrate that the virtual and physical prototyping systems appeared to be as effective as each other in producing insights for sustaining innovations. Yet, when attempting to elicit an understanding of customer requirements for the potentially disruptive innovation, virtual prototyping was significantly less effective in facilitating the identification of product features and functions that address the 'delighter' customer requirements (Kano, 1979, 1982, 1983). As customer 'delight' is a significant factor in the success of disruptive innovations, the final part of this paper contends that virtual prototyping could in fact stifle a corporate entrepreneur's evaluation of opportunities with the potential to deliver disruptive innovation.

OPPORTUNITY EVALUATION

The process of *opportunity evaluation* plays an important role in the opportunity recognition process (Shane, 2000, 2003; Ardichvili et al., 2003; Baron, 2006) of corporate entrepreneurs (Leifer, et al., 2000; O'Connor and Rice, 2001; Rice et al., 2001; Gordon, 2007). It has been shown that when successful entrepreneurial technicians and engineers *evaluate* their radical technical or business insights to be valuable, they routinely adopted processes to bridge their insights into the opportunity recognition processes of other managers, whose positive *evaluations* in turn can generate corporate support (Leifer, et al., 2000; O'Connor and Rice, 2001; Rice et al., 2001). Similarly, the Design-Build-Test (DBT) cycle of product development (Burgelman et al.'s (1996) prominent technology management conceptualisation of the opportunity recognition process) highlights the importance of opportunity evaluation through the continuous testing and re-testing of design iterations. Our analysis of these contributions reveal that the general objectives of opportunity evaluation are three-fold: (i) to assess the new concept's fit with organisational capabilities and strategy, (ii) to assess technical feasibility and performance, and (iii) to assert a commercial demand through a satisfaction of customer requirements.

Disruptive Innovation

Corporate entrepreneurs must be able to recognise and evaluate two broad types of opportunities (Christensen, 1997; Christensen and Overdorf, 2000; Christensen and Raynor, 2003): (i) opportunities that can offer sustaining innovations – minor or major improvements to established value propositions – and (ii) opportunities that can offer disruptive innovations – products based on alternative trajectories of development, that have the potential to create new wealth with new value propositions, that eventually force the restructuring of existing value propositions and disrupt the established terms of economic engagement within established industries.

The exploitation of a potentially disruptive innovation can provide a business with significant new wealth, substantial long-term value and increased long-term survival (Abernathy and Clark, 1985; Carrol, 1985; Tushman and Anderson, 1986; Christensen, 1997; Walsh and Kirchhoff, 2002); however, it can also provide an opportunity for economic failure (Tushman and Anderson, 1986; Christensen, 1997; Van de Ven, 1986). Hence, whilst opportunities to exploit potentially disruptive innovations are accompanied by the potential of breakthrough value, they are also accompanied by higher risks than sustaining innovations; this increases the pertinence of the opportunity evaluation process and makes its objectives difficult to achieve (Bucher et al., 2003).

As a disruptive innovation is likely to proceed in divergence to an established firm's development routines and strategic directions (Tushman and Anderson, 1986; Christensen, 1997; Walsh and Kirchhoff, 2002), a positive evaluation of a potentially disruptive opportunity's fit with organisational capabilities and strategy is likely to be difficult (Ahuja and Lampert, 2001).

Likewise, disruptive innovations often capitalise on materials, components and processes that are less familiar to an industry's incumbents (Bucher et al., 2003), which are often of lesser quality along the industry's established performance dimensions (Christensen, 1997). Consequently, a manager's dominant logic (Prahalad and Bettis, 1986) and traditional assessment metrics can leave them ill equipped to effectively evaluate the technical feasibility and performance of a potentially disruptive innovation (Tripsas and Gavetti, 2000; Ahuja and Lampert, 2001, Thomond, Lettice and Herzberg, 2004; Thomond and Lettice, 2006).

Finally, it is essential to deliver effective customer based opportunity evaluations: a form of customer testing (Tidd et al., 1997) that generates clear distinctions between market segments and an evaluation of commercial demand. A better understanding of customer requirements underpins this objective, and is said to be perhaps one of the most difficult challenges faced by the corporate entrepreneur tasked with evaluating an opportunity with disruptive potential (Cooper et al., 2001). Whereas customers for sustaining innovations are well known and can voice their demands, initial customers for potentially disruptive innovations are likely to be groups with which an industry's incumbents have had little experience (Bower and Christensen, 1995; Christensen and Raynor, 2003) and these customers are unlikely to be aware of all their unmet needs (McDonald et al, 2001; Cooper et al, 2001). As the critical nature of understanding customer requirements warrants further analysis, we explore some of the problems and solutions below.

Understanding Customer Requirements

It is important for Corporate Entrepreneurs to test and understand customer requirements because how well they are or can be satisfied by new opportunities will form the basis of customer demand (McGrath and Macmillan, 1995; McDonald et al., 2001).

The fact that not all customer requirements are equal or even explicit, for that matter, adds complexity to the task of opportunity evaluation. Kano's (1979, 1982, 1983) analysis of the quality management field through the lens of Fredrick Herzberg's 'Motivation-Hygiene Theory' (1966) reveals there are three levels of customer requirement. Firstly, he demonstrates that customers have 'must-be' requirements. If a product lacks features and functions that address a customer's must-be requirements then they will feel a strong sense of dissatisfaction. If, however, the features and functions that address must-be requirements are well developed, customers will feel no more than neutral as they expect such features to be present. Secondly, a customer's level of satisfaction can be proportional to the development of specific features and functions that address 'satisfying' requirements (initially referred to by Kano as one-dimensional customer requirements). If 'satisfying' features and functions are present and well-developed, customers will feel highly satisfied, if not, they will be dissatisfied. Finally, customers are said to have 'delighter' requirements (initially referred to by Kano as attractive customer requirements). When a product's features successfully address these requirements the customer will experience delight; however, as customers are generally unable to articulate what delights them and are generally unaware that such features are possible, their absence does not impact satisfaction levels.

Kano's typology of must-be, satisfying and delighter requirements, enables the assertion that a product based disruptive innovation is a bundle of features and functions of which a significant cluster are novel delighters for the market. For example, millions of customers were delighted by the Sony Corporation's introduction of the Walkman, in particular its novel feature of extreme personal portability (IEEE, 2005). Before the Walkman's emergence, people were not dissatisfied by the mainstream alternatives that lacked such portability (IEEE, 2005). However, after the emergence of the Walkman, the delighting portability feature soon became the benchmark to which alternative products were unflatteringly compared, the results of such comparisons drove the Walkman's success.

The Sony Walkman example also illustrates an often overlooked feature of Kano's model of customer requirements: the maturing of customer requirements and normalisation of product features and functions (Evans, Burns and Barrett, 2002). For example, a feature that creates customer delight will soon become more common place and shift towards simply satisfying the customer. Likewise, a feature that addresses satisfying requirements will eventually become fully expected and integrated into the customer's list of must-be features. This process of normalisation supports the assertion that a disruptive innovation's initial success is based upon novel delighter features, and whilst it is these features that can help pioneer market disruption, it is also these features that become the future target of sustaining innovation (Christensen, 1997) – as customers' delighter requirements soon mature (Bolster, 1993) into satisfying and must-be requirements.

Consequently, access to tools that can deliver a better understanding of customer requirements, (including how they are prioritised by different market segments and the degree to which they are already satisfied), will help provide credible information that corporate entrepreneurs can use to make design trade-offs to enhance the desirability of new product opportunities (Urban and Hauser, 1993; Ulwick, 2002). By analysing customer complaints and conducting well executed market research managers will highlight the features and functions of a product that address the customers' 'must be' and 'satisfying' requirements respectively (Evans et al, 2002). However, in the case of complex new products and disruptive innovations, potential customers are generally unaware of, or unable to articulate, their requirements (Tidd et al., 1997). When customers are unable to articulate their needs, traditional market research tools become redundant (Trott, 2001; Ulwick, 2002). A recent analysis of the car manufacturer Nissan's opportunity recognition processes revealed that listening to the voice of the customer with market research is actually detrimental to the identification of features that 'delight' customers (Garside, Burns and Evans, 2002).

There are two primary inhibiting conditions that frequently occur when customers are asked to think about products or situations with which they have had little to no experience (Leonard, 2002; Leonard and Rayport, 1997), both explain why traditional methods for understanding a customer's range of requirements are ineffective in the context of disruptive innovation. Firstly, customers may experience 'functional fixedness'; this is where they fixate on the way they normally use things and are unable to imagine alternative functions. Likewise, customers may suffer 'contradictory needs', where they struggle to discuss new product alternatives because they cannot imagine solutions to their contradictory demands.

To overcome the problems with understanding customer requirements in evaluating opportunities with the potential to deliver disruptive innovations, managers can employ different forms of rapid experimentation to enable fast learning about markets (although Tushman and O'Reilly (1996), Christensen (1997) and Christensen and Raynor (2003) demonstrate that the majority of industry incumbents lack this capability). *Expeditionary marketing* (Hamel and Prahalad, 1994), which bares some similarity to *discovery driven planning* (McGrath and Macmillan, 1995), encourages corporate entrepreneurs to learn about their markets as quickly as possible through experimentation with real products and customers. However, critics of expeditionary marketing and discovery driven planning assert that it is often poorly implemented and can be risky and wasteful of resources (Tidd et al, 1996). Alternatively, a less expensive and reduced risk approach to opportunity evaluation is offered by empathic design (Leonard and Rayport, 1997). The empathic design process employs anthropological observations to help uncover elusive unarticulated customer needs. However, critics of empathic design claim data collection and analysis processes are rarely implemented in a rigorous scientific fashion (Evans et al, 2002). In response to these strengths and weaknesses, Garside et al. (2002) and Evans et al (2002) developed a combined experimental-empathic method to probe customer requirements and evaluate new opportunities. They increase the rigour of observing customer behaviour, by applying a 'Kano Customer Requirements Analysis', whilst simultaneously utilising an expeditionary approach to the development and customer-testing of prototypes.

Prototyping

Prototyping has long been used in the new product development field (Gordon and Bieman, 1994), for example, the previously mentioned DBT cycle (Burgelman et al, 1996) propagates the importance of developing design alternatives into prototypes that are evaluated to generate feedback for the design stage of another DBT iteration.

We categorise prototyping into two broad forms: physical and virtual. Physical-prototyping is the process by which a physical replica of a new product design is generated and evaluated; the complexity of the replica will range from a rudimentary mock-up through to a fully-working model. Virtual-prototyping, by contrast, allows a new design to be generated and evaluated in a computer environment, generally a desk top, without the need to create a physical model. Virtual prototyping first emerged as a tool to visualise a product before a rudimentary physical mock-up was made in the very early stage of new product development (Burgelman et al, 1996).

The role of prototyping in aiding opportunity evaluation has received over two decades of favourable support by academics and managers alike (Boehm, Gray and Seewaldt, 1984; Wohlers, 1991; Gordon and Bieman, 1994). In fact, the facilitative impact of prototyping can be linked directly to the specific and previously mentioned objectives of opportunity evaluation (Burgelman et al., 1996; Tidd, Bessant and Pavitt, 1997; Leifer, et al, 2000; Kelley and Littman, 2001). Firstly, prototypes can be used to help managers to test whether the internal context provided by their organisation's capabilities and strategy will support the production of the prototyped product (Gordon and Bieman, 1994; Yan and Gu, 1996; Kelley and Littman, 2001, Rice et al., 2001). Secondly, prototypes can be used to test the capabilities and thresholds of the component technologies and materials within a new product (Gordon and Bieman, 1994; Yan and Gu, 1996; Burgelman et al., 1996). Finally, and importantly for this paper, prototypes can be used to facilitate critical customer testing, or customer based opportunity evaluation (Evans et al., 2002). By using prototypes to gain an understanding of customers' reactions to the features of a new product opportunity, corporate entrepreneurs can help mitigate market uncertainties (Cooper et al., 2001; Burgelman, et al., 1996; Tidd, Bessant and Pavitt, 1997). Moreover, in the particular context of potentially disruptive technologies, physical prototypes have been shown to elicit invaluable knowledge when used in field work, both within the potential market and within parallel markets (Cooper et al., 2001). It would seem that physical prototypes help customers to challenge their functional fixedness and contradictory needs, thus helping corporate entrepreneurs to make their assumptions clear when evaluating market demand.

The emergence of increased computing power and a continual drive for material and time efficiencies have steered a growth in the use of virtual prototyping (Gordon and Bieman, 1994; Yan and Gu, 1996; Kelley and Littman, 2001). From an initial position as simple computer imagery used in very early evaluations, virtual prototyping systems are now used in activities that would have previously been the domain of more expensive physical prototypes (Kelley and Littman, 2001). The benefits of using virtual prototyping to help managers evaluate their firm's production capabilities and materials knowledge are now well documented (Burgelman, et al., 1996). Likewise, modern virtual prototyping approaches increasingly include computer simulations that deliver new product capability and threshold analyses. Moreover, researchers have demonstrated that valuable customer reactions and critical customer based opportunity evaluations can be generated by showing customers virtual prototypes of innovations that sustain the development of familiar products (Burgelman, et al., 1996; Tidd, Bessant and Pavitt, 1997; Kelley and Littman, 2001).

However, when using several iterations of a virtual prototype, 'creatives' at Disney, the global media and entertainment group, failed to convince executives of the potential in their highly disruptive "Animal Kingdom" concept. It wasn't until the creatives surprised their seniors by unveiling a caged tiger in a meeting room, that Disney's executives remembered the gravitas and delight of being close to live animals (Allen et al., 1999). The Disney experience, along with other anecdotal evidence suggests that virtual prototyping may even be counter-productive to the evaluation of potentially disruptive opportunities (Allen et al., 1999; Kelley and Littman, 2001). In fact, there remains a lack of compelling empirical data to demonstrate whether virtual approaches to prototyping are as effective as physical systems in eliciting customer feedback and customer based opportunity evaluation during the development of potentially disruptive innovations. It is this gap in the literature that our research seeks to address. In particular we seek to answer the question: are virtual prototyping systems as effective as physical prototyping systems in supporting customer based opportunity evaluations and eliciting customer requirements during the early development of potentially disruptive innovations?

RESEARCH METHODOLOGY

Research design and sample

An experimental design was employed in order to assess whether virtual prototyping systems are as effective as physical prototyping systems in customer based opportunity evaluations, specifically in eliciting a deeper understanding of 'customer requirements' during the early evaluation of potentially disruptive opportunities. The methodology was designed to generate both descriptive and explanatory insights and borrowed from the combined experimental-empathic method developed by Garside et al. (2002) and Evans et al (2002) to probe customer requirements and evaluate new opportunities. The data for this study were collected using a self report questionnaire that was completed in experimental conditions in reaction to two prototyped products.

When selecting an appropriate setting for the current investigation, it was decided that the adoption of a real world industry problem would increase the validity of the experimental approach. For the last two years, the mobile phone industry has witnessed the saturation of European markets and a slowing of global growth across the sector (Lewis, 2005). Moreover, the only significant breakthrough profits generated during this time, were by firms such as Japan's TuKa that pioneered an unforeseen low-end market disruption with the introduction of simplistic phones for technophobes (Lewis, 2005) - a highly appropriable product category. Today, the industry's leaders are actively communicating their intent to understand which technology or convergence of technologies will deliver the next breakthrough profits (Lewis, 2005). Industry executives do not yet know how they are going resolve this issue, nor do they know if recent high-tech developments, such as 3G, will provide their companies with a market lead, hence they remain unclear on how best to invest their resources for the future (Lewis, 2005). As the mobile phone sector has reached a level of maturity that is encouraging a number of its important players to actively look for opportunities with disruptive potential, and as they do not know yet how they are going to rise to this challenge, it was chosen as an appropriate setting for the current investigation into customer based opportunity evaluations of potentially disruptive innovations.

To control for the effects of market segment heterogeneity on opportunity evaluation, a stratified sampling (Neyman, 1934; Lohr, 1999) approach was employed by setting the research within a specific market niche of the mobile phone industry. The 'power-user'[4] stratum was selected: the top 15% of a network provider's customers, who make the most use of their phone's functions and their operator's services. The sample population for this investigation was randomly drawn by placing of an advert in a locally respected newspaper which simply stated: *"Would life and work without your mobile phone be impossible? Do you consider yourself to be a 'high-end' mobile phone user, a network operator's dream? If so, and you're interested in giving free feedback on two new mobile phone designs, email…"*. A leading mobile network operator's industry classification of 'power-users' was used to screen self reported mobile phone use (by number of services regularly accessed, age, educational background, and number of calls and texts per month) in order to build a stratum with matching characteristics.

Survey method

To control for experimental bias caused by probing a potentially disruptive innovation in isolation, two different innovative mobile communication concepts were prototyped: the first was a control, and offered sustaining innovations in relation to market leading devices, the second was of a potentially disruptive communications device. In brief, our method involved (i) developing a physical and virtual prototype of each device; (ii) presenting both devices to the participants in either a physical or virtual condition; (iii) gathering survey data from each participant regarding each of the devices' key features and functions; (iv) aggregating the survey data and plotting the results onto graphics which illustrated the type of customer requirement (must-be, satisfying, or delighter) that each feature and function addressed; and (v) the comparative analysis of the aggregated data to interpret the effectiveness of each prototyping approach. Each step of this method is described below, the final step is presented I the results section.

(i) Developing new communication concepts and their physical and virtual prototypes: To develop both the sustaining and potentially disruptive innovations, and to ensure that the prototypes could be compared, the primary product features of mobile phones and communication devices were listed by a panel of industry and product development experts. The features were clustered into

customer requirements and the primary variables of each were listed and ranked. The top 11 traditionally most important customer requirements (see tables in the results section) were used as a baseline to develop the following two new concept communication devices (vastly improved batteries are demanded by all customers so it was presumed that both products offered this feature in equal ammounts). *Communication Device 1 (CD1)* was assumed to be a sustaining innovation as rated by the panel of industry and product development experts. It offered sustaining improvements along well established technology trajectories of an existing and familiar mobile phone technology, with some radical improvements to features such as 3G internet and music storage (in fact, it was a 'de-branded' state-of-the-art model from a leading manufacturer). *Communications Device A (CDA)* was assumed to be a potentially disruptive innovation, as rated by a panel of industry and product development experts. In many ways it is best to think of this concept more like a low-performing lap-top (notebook) personal computer with telecoms, digital camera and music functionality and less like as an advance mobile communications device. It was designed to offer a novel combination of existing technologies into a non-sustaining platform. In particular, the device embraced two product features that were counter to industry-standard technology trajectories: size and weight. For example, the main device had dimensions of 9x14x2cm and weighed 690g. It was said that CDA could be carried in a purpose designed high-fashion bag or 'body-strap' (or alternatively a large pocket). However, whilst it worked against the dominant performance improvement metric of 'the smaller and lighter the better', CDA contained other features that could be seen as radical or even somewhat discontinuous leaps in directions that power-users often indicate as desirable in traditional market research (Walko, 2005). For example, the device utilised 'blue-tooth' links to a sophisticated ear-piece with a non-intrusive microphone and a wrist mounted microphone for speaking in windy conditions. It also utilised a high quality 8.5x13cm touch screen display for all interactivity features (including the option to use an on-screen QWERTY keyboard instead of predictive text). The mass memory allowed for 'i-pod quality' storage and playback of music, photos and videos from a 3 mega-pixel full flash camera and video recorder, advanced contact phone and address book and document storage and editing with basic Microsoft office software, including email and internet.

The virtual prototypes of each device consisted of accurately drawn CAD images, which could be manipulated to be seen from all angles on a computer screen. The images were presented alongside wiki-based commentaries on each product's features and functionality; these also contained diagrams of images as they would be seen on the devices. The commentaries were not framed as sales pitches, they were rational and non-emotive. Neither physical prototype was functional. To control for the fact that the sustaining innovation, CD1, was in truth a real product, it was deactivated and CDA was given an elegant design along with a realistic feel and weight. Both physical prototypes were given to participants with written guidelines on the functionality printed directly from the virtual prototyping system..

(ii) Presenting the devices to the participants: The experiment employed four groups of participants, A, B, C and D, each group contained an equal number of participants representing 'power-user' customers. Participants and groups were matched for age and other attributes. Groups A and B were presented with the virtual prototypes of both products CD1 and CDA, and groups B and C the physical prototypes. To control for order effects, Group A was presented with CD1 and then CDA, Group B was presented the devices in reverse order. Group C was presented with CD1 and then CDA and Group D saw these in reverser order. In both the virtual and physical prototype conditions, information regarding the each of the product's features and functions was read to the participants by a research collaborator, they could also navigate through the information themselves, and they could guide their own experience of interacting with the prototypes.

(iii) Gathering survey data (survey instruments and variables): Each participant was given five minutes to familiarise themselves with the prototype, they were then presented with a survey and asked to complete it whilst they still had the product to hand. Thirty minutes was given to each prototype condition. The primary survey instrument used in this research was a 'Customer Requirement Kano Questionnaire'; it was adopted for two reasons: (i) it is a proven and validated approach for eliciting product focused "customer feedback" (see Berger et al., (1993) for a comprehensive description of this questionnaire and process), and (ii) it was also embraced by the experimental-empathic methods developed by Garside et al. (2002) and Evans et al (2002) as a highly rigorous technique to probe customer requirements and evaluate new opportunities. The Kano questionnaire contains of a query for each feature or function of the product under consideration and it is presented in two parts. The first part asks a 'functional' question: 'how do you feel if that feature is present in the product?'. The second part asks a 'dysfunctional' question: how do you feel if that feature is not present in the product? The customer can traditionally answer each question using one of five 'standard answers': I like it that way; It must be that way; I'm neutral; I can tolerate it; I dislike it. To avoid the confusion

that can surround the standard answers, in particular why the answer ‘I like it that way’ is stronger than ‘It must be that way’ (Blauth, Richter and Rubinoff, 1993), we adopted Bolster’s (1993) recommended question amendments. Hence, ‘It must be that way’ was replaced by ‘I expect it’. Moreover, a self-stated importance question (Urban and Hauser, 1993) accompanied each Kano query. This allowed the participants to rate the importance of each of the product’s features on a scale from “not at all important” (1) to “extremely important” (9), where “important” was placed centrally (5). Moreover, it was used to allow the researchers to identify additional patterns in the survey data (Urban and Hauser, 1993).

(iv) Aggregating the survey data and plotting customer requirements graphics: In a slight break with tradition, DuMouchel’s (1993) more sophisticated weighted-averaging analytical approach was adopted to aggregate the survey data (see Berger et al., (1993 p20) for a comprehensive description of this process). Traditionally, the simplest way to categorise a feature or function is to gather all the individual participants’ responses, to categorise them according to Table 1 and to use the statistical mode, *i.e.*, the most frequent response.

Table 1. Kano Evaluation Table - adapted from Kano (1983) and Berger et al. (1993)

Customer requirements		Dysfunctional				
		I like it	I expect it	I'm neutral	I can tolerate it	I dislike it
Functional	I like it	Q	D	D	D	S
	I expect it	R	I	I	I	M
	I'm neutral	R	I	I	I	M
	I can tolerate it	R	I	I	I	M
	I dislike it	R	R	R	R	Q

Customer Requirement Key:
D: Delighter — *S: Satisfier “One-dimensional”*
M: Must-be — *Q: Questionable result*
I: Customer Indifference — *R: Reverse (the functional and dysfunctional phrasing my be inverse to customer requirements*

However, the weighted-averaging analytical approach promotes the use of a scaler score attributed to the functional answers (4 for ‘I like it’, 2 for ‘I expect it’, 0 for ‘I'm neutral’, -1 for ‘I can tolerate it’ and -2 for ‘I dislike it’) and the dysfunctional answers (-2 for ‘I like it’, -1 for ‘I expect it’, 0 for ‘I'm neutral’, 2 for ‘I can tolerate it’ and 4 for ‘I dislike it’). The logic for the asymmetric scale is that must-be, satisfying and delighter responses are stronger that indifferent or questionable results. By using the scaled scores a weighted average response can be calculated for each product feature and function. The primary benefit of DuMouchel’s approach is that it avoids a mode based analysis, and the quasi-arbitrary assignment of the features and functions along their respective curves within Kano’s much discussed and often confused ‘must-be, satisfying, delighter diagram’. The weighted-averaging analysis combined with the results of the self-stated importance questions, allows for a more sensitive and realistic representation of the aggregated survey data and a more sophisticated plotting of features to Kano’s typology of customer requirements.

RESULTS & DISCUSSION

Two-hundred and fifty-one people responded to the advert to take part in this study. Ninety-eight participants were validated as ‘power-users’ and invited to take part in the investigation. They each selected a date and time that best suited them within a four month period of responding. In total, 80 participants took part in the experiment by attending one 1-hour session each in a city centre office: 42 females (aged 24-38), 38 males (age 25-37), their ethnic mix was representative of the local city from which each participant was resident, which was in turn generally representative of most prosperous cities world-wide. There is no reason to believe that any of the participants knew one another. We attribute our high response rate and low drop-out rate to the ‘power users’ committed nature to their much used products. The 80 participants were dived into four groups of 20 as previously described, 71 completed their Customer Requirement Kano Questionnaires within 24 minutes for each product type; the remainder comfortably completed the task within the allotted time.

To illustrate how the data were aggregated, Table 2 illustrates the participants’ responses to the functional and dysfunctional queries regarding CD1’s digital camera quality in the virtual prototyping condition, the numbers represent the frequency of responses. Table 3 presents the fully aggregated data.

Interpreting the data

By using DuMouchel’s (1993) adaptation of the Kano methodology, average functional and dysfunctional scores for each feature of each product in each condition were calculated and plotted onto a point within a functional-dysfunctional matrix. The closer a point falls to one of the four labelled corners (which represent Kano's three archetypal customer requirements plus a fourth of 'indifference'), the more unanimous the survey respondents must have been in their views (DuMouchel, 1993). Conversely, disagreement amongst the participants is represented a point that is close to the very centre of the matrix.

Table 2. An example of raw aggregated data for the digital camera quality feature of CD1, assessed by participants in the virtual prototyping condition.

Ref	Feature	Variable Summary	Functional Query: I like it	I expect it	I'm neutral	I can tolerate it	I dislike it	Functional average	Dysfunctional Query: I like it	I expect it	I'm neutral	I can tolerate it	I dislike it	Dysfunctional average	Average importance rating
3	Photo	Quality (improved vs. less mega pixels)	3	9	8			1.5			1	2	17	3.6	2.5

Four primary functional-dysfunctional matrix plots were developed from the data: two for CD1 and two for CDA, allowing the virtual and physical prototype conditions to be directly compared. This represents a more sophisticated analysis that the traditional approach of categorising each product feature into a must-be/satisfying/delighter typology by mode.

Table 2. The top 11 most important customer requirements of mobile communication devices with aggregated Kano evaluation data (functional, dysfunctional) and importance rating averages.

Feature Ref	Customer Requirement	Key Variable	CD1 Physical Proto F'ave	D'ave	I'ave	CD1 Virtual Proto F'ave	D'ave	I'ave	CDA Physical Proto F'ave	D'ave	I'ave	CDA Virtual Proto F'ave	D'ave	I'ave
1a	Portability	Weight (Lighter vs. heavier)	0.5	1.5	3.0	0.2	1.8	3.5	2.4	0.2	6.5	0.4	0.4	6.2
1b	Portability	Size (smaller vs. larger)	1.0	0.5	2.7	0.2	0.9	3.5	2.6	0.1	6.6	1.1	1.2	6.0
2a	Video	Quality (improved vs. lower quality screen pdi)	1.0	1.4	2.6	0.2	1.8	2.2	2.4	3.0	6.9	2.2	2.5	3.8
2b	Video	Screen size (larger vs. smaller)	1.6	3.6	3.0	0.9	3.1	3.0	3.4	3.9	6.4	2.5	3.5	5.1
3	Photo	Quality (improved vs. less mega pixels)	1.8	3.5	4.1	1.3	3.5	3.8	3.4	3.9	7.5	2.7	3.6	6.8
4	Music	Audio output quality (Improved vs. lower)	1.0	2.5	4.1	1.0	2.1	3.2	1.7	3.2	5.8	1.7	3.4	4.1
5a	Memory	Music (Larger vs. lower)	2.1	3.7	5.4	1.8	3.1	6.1	3.1	1.0	8.1	2.0	1.2	7.5
5b	Memory	Photo (Larger vs. lower)	1.6	2.8	5.0	1.2	2.5	5.7	3.0	2.0	8.0	2.7	3.4	6.3
5c	Memory	Video (Larger vs. lower)	1.0	2.8	3.5	1.0	2.3	3.4	3.1	1.7	5.0	2.7	2.9	5.1
5d	Memory	Contacts (Larger with more detail vs. less)	1.1	1.2	3.4	0.9	1.0	2.4	2.7	2.6	5.2	2.0	1.9	4.4
6a	Data sharing	Phone to phone (Improved vs. slower)	1.2	2.4	4.0	1.3	1.0	3.8	3.4	1.1	6.9	2.1	1.3	7.0
6b	Data sharing	With PC (improved vs. none)	1.3	2.5	4.5	1.7	2.2	5.9	3.2	1.2	8.0	2.6	2.1	8.3
7a	Customizability	Ringtone quality (better vs. less)	0.9	0.5	2.7	0.2	0.3	2.0	0.3	0.8	3.0	0.2	0.3	1.8
7b	Customizability	Ringtone choice (more vs. less)	0.8	0.4	2.3	0.3	0.4	2.6	0.6	0.8	2.3	0.5	0.3	1.7
7c	Customizability	Wallpaper options (more choice vs. none)	0.4	0.2	1.9	0.3	1.1	1.4	0.1	0.4	1.6	0.0	1.0	1.4
8	Email	Size (smaller vs. larger)	0.7	1.2	3.9	1.6	2.4	4.4	2.2	2.9	7.8	2.3	3.2	6.0
9	Internet	up/download (faster vs. slower)	1.4	2.5	4.4	1.4	2.0	6.4	3.6	3.3	7.7	3.0	3.3	7.2
10	Calls	Hands free (wireless vs. with wires)	1.2	2.2	2.0	0.4	1.8	2.7	1.8	3.5	4.0	1.8	3.2	3.1
11	Texting (SMS)	Input method (improved vs. less functionality)	0.2	0.3	2.0	0.0	1.4	1.2	3.1	1.7	6.0	1.8	1.8	5.8

F'ave = functional average **D'ave = dysfunctional average** **I'ave = average importance rating**

(i) A sustaining innovation (CD1) in virtual and physical prototyping conditions: 'the control': The matrices plotting average functional and dysfunctional scores for CD1 in the virtual and physical prototype conditions display some insignificant and minor differences (space restrictions prevent these being shown). The primary difference was that physical prototyping condition appeared to allow participants to generate marginally clearer insights, in that they labelled particular 'must-be' features

more categorically. However, the lack of a significant variation in feature ratings allows us to state that both the virtual and physical prototyping conditions were as effective as each other in uncovering customer requirements and generating a customer based opportunity evaluation of CD1.

(ii) A disruptive innovation (CDA) in virtual and physical prototyping conditions: 'the experiment': The matrices plotting average functional and dysfunctional scores for CDA in the virtual and physical prototype conditions (Figure 1), show that both prototyping techniques were as effective as each other in allowing the participants to identify the features of CDA to which they were indifferent (the customisation features of the device). However, that is where the similarity in the survey responses stops.

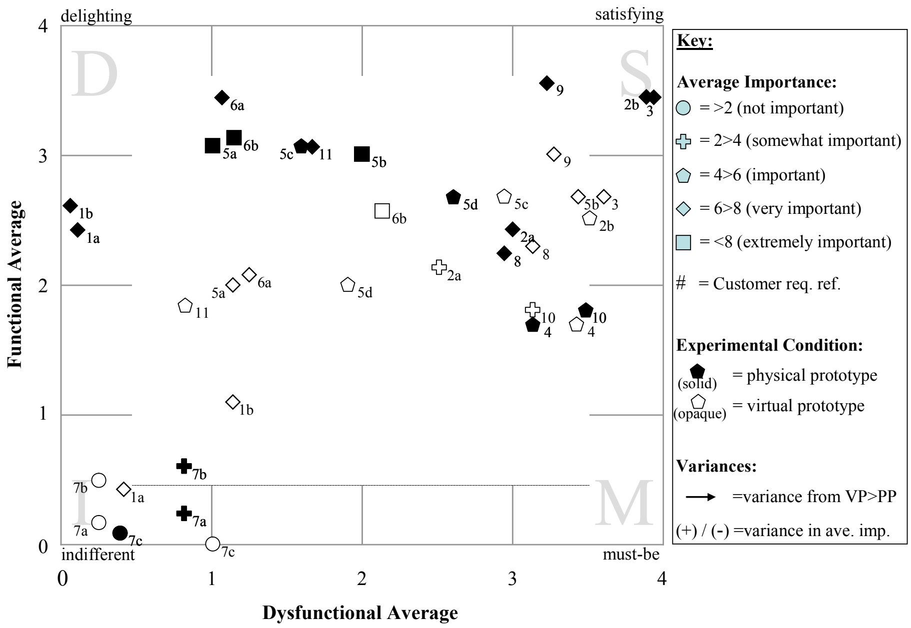

Figure 1. A plot of average functional and dysfunctional ratings for CDA in the virtual and physical prototype conditions.

The two techniques elicited vastly different responses from their participants. In particular, the cluster of features that were rated as "delighters" in the physical condition showed significant variance in the virtual condition, where they were rated as 'mixed results' or 'satisfying' at best (Figure 2). In the physical prototyping condition, the participants seemed to more clearly associate CDA's large proportions in size and weight with the products ability to actually deliver on the promise of a discontinuous leap forward in features that would normally satisfy the power user. Hence, the weight (1a) and size (1b) of the device were rated as delighters along with memory intensive functions such as a larger capacity for music (5a), high quality photos (5b) and video capture and conference recording (5c). Moreover the robust feel of the device was reported to generate participant belief in its peer to peer data sharing feature (6a) and its device to desk-top back-up and down-load system (6b). Participants in the virtual condition, on the other hand, appeared unable to shake their 'functional fixedness' (Leonard, 2002) regarding size and weight, which is why they remained unconvinced regarding the potential of features that their counterparts were delighted with in the contrasting physical condition.. Hence, whilst they were still able to identify some memory intensive features as satisfying, they uncovered 'contradictory needs' (Leonard, 2002) regarding the desire for a significant leap forward in some features' performance, whilst still demanding a small, light device.

Analysis of Figure 1 also reveals that the physical prototype helped to increase the clarity with which participants saw the functions and features that addressed their satisfying requirements. Whereas an extensive contact address book and networking system (5d) created disagreement amongst those in the virtual prototype condition, those who interacted with the physical prototype seemed to better understand its relation to their explicit need for such a system. Likewise, the physical prototype allowed the participants to imagine the possibilities of vastly improved video quality (2a), video screen size (2b), photo quality (3) and internet access (9). Whilst each of these latter features were also rated satisfying in the virtual prototype condition, it was once again the participants' inability to let go of the size and weight issue that seemed to force an element of disbelief into their minds regarding CDA'a ability to deliver on the promise that was described.

In sum, it would seem that the primary difference between the virtual and physical conditions was that the latter enabled the participants to generate significantly clearer insights into CDA. This appears to indicate that the physical prototyping condition helped the participants to develop a better relationship with the product's features and how they would work in a real world setting.

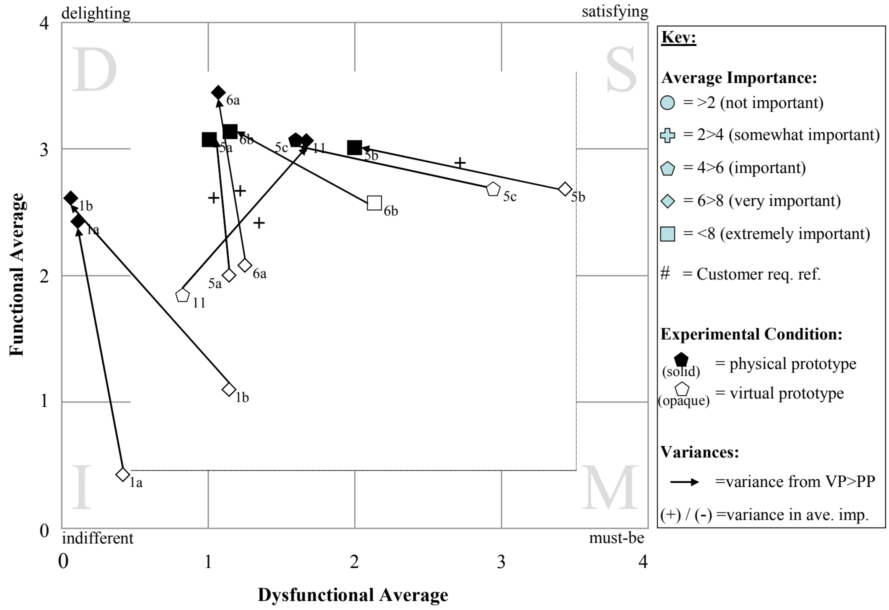

Figure 2. A plot of average functional and dysfunctional ratings for CDA: the identification of delighters with physical prototyping.

If it was possible to extrapolate a generalisable result from our study, the findings presented here would show that: (i) virtual prototyping is a less effective method than physical prototyping in uncovering customer requirements and (ii) it is better to use physical prototyping to generate customer based opportunity evaluations for potentially disruptive innovations. However, whilst such a statement would seem to hold true within the experimental conditions that we created for CD1 and CDA, we appreciate that it is a false statement without further experimentation with more participants and in more product categories. Moreover, there are a number of flaws in our experimental approach that must be addressed. We discuss these issues below.

Further research

Our methodology enabled us to observe how a group of 80 self confessed and validated mobile phone 'power users' evaluated and interacted with two new mobile communication concepts. Prototyping helped us to complete this in a manner that avoids the risks of full product development and our survey mechanism helped us to generate insights into the participants' requirements and their likely 'lived experience' with these products in the future. Our results offer a contribution that favours the use of physical prototyping in the context of evaluating disruptive opportunities. Yet, before we can begin to validate our claim, we must develop further statistical analyses and address a series of other issues in future iterations of this study. For example, we acknowledge that a well received prototype is not always a reliable predictor of purchase. More research is needed to investigate the relationship between favourable new opportunity evaluations and sales.

Moreover, the analysis reveals that the order in which the prototypes were presented to the participants often influenced the importance placed on specific product features. For example, 'video memory' (5c) was rated with low levels of importance when CD1 was presented first, however, if presented after CDA, with its "beyond 'i-pod' quality memory", the participants became more demanding of CD1 by increasing their ratings of feature importance. This was more observable if the feature offered discontinuous changes to the communication device. Hence, more analysis is needed to understand and reduce ordering effects.

With regards to the survey mechanism, some participants reported being confused about the 'dysfunctional questions' when dealing with the radical improvements offered by CDA. For example, when considering the dysfunctional questions for CDA's photo memory (5b), some participants did not know whether this meant less functionality with regards to the CDA offering, and, therefore, a larger memory than a traditional mobile phone device, or, whether this meant even less than a standard device. We will have to revise our clarifying statements to avoid this issue in future.

We also noticed that there is an interrelatedness of product features that is difficult to analyse. As it is not possible to consider the features of either device in isolation, the clarity of our conclusions remains to be tested. For example, in one of the physical prototype conditions, 11 participants and 8 participants rated the larger video memory feature of the CDA as 'liked' and 'expected' respectively. However, this feature is only possible if they are also accepting of significant increases in size and weight. Equally, participant support and approval of increased size and weight is only possible because of the unique features offered by CDA. More work and analysis is needed to further unpick the interrelatedness of features; without such knowledge, a product development team could damage its returns and reputation by mistakenly focusing on one feature without the inclusion of another.

Regarding the virtual prototype condition, it is difficult to state with complete confidence that the CAD drawings matched the quality of the physical prototypes. This may have influenced the results. Moreover, a facilitator read a document regarding the functions and features of both products to the participants. Perhaps this was process simply more tedious for CD1, as the participant had less new functions to 'play with'; self guided discovery may overcome this factor.

The current experiment employed stratified sampling method in an attempt to reduce sampling error. A random sample of 40 participants took part in each primary condition (physical and virtual prototyping), they represented the "power user" stratum, for mobile phone usage, age and educational background. Whilst we are reasonably confident that the stratum represented the "power user" population and that each group was painstakingly matched, we cannot be completely sure that our observed differences were simply due to differences between the groups. Moreover, we now believe that our presumption that CDA (the potentially disruptive innovation) would primarily delight power users led us to overlook insights that could be gained from customer based opportunity evaluations in other market segments. In future iterations of this experiment, we would like to involve a broader random sample. By being more inclusive in our data collection we may find other distinct market segments who would be delighted by the CDA for other reasons - a of test correlation between responses and the demographic data would allow us to check for the existence of other market segments.

Finally, whilst the results of our experiment are encouraging and may be used to raise questions about today's industrial practice, we recognise that their lifetime is limited. The emergence of technologies that can blend a three-dimensional virtual environment into a physical space, such as the University of Stuttgart's "Virtual Reality Cave", will one day be combined with haptics technologies making the questions probed by our study completely redundant. In the mean time, before these technologies are perfected, we would like to add a virtual reality environment as a third condition to our experimental approach.

CONCLUSION

Due largely to the drive for efficiencies in both time and cost, managers in today's businesses are adopting virtual prototyping techniques in favour of the relatively slower and more expensive production of physical models. This shift to virtual prototyping has been supported by the development of sophisticated computer modelling. Yet, there has been a general failure to investigate whether all the benefits of physical prototyping remain uncompromised by the adoption of virtual techniques. Although empirical data demonstrates that virtual prototyping systems are more efficient than physical prototyping when evaluating sustaining innovations, there is a lack of data to prove this to be true of disruptive innovations. Anecdotal evidence suggests that virtual prototyping systems compromise a potential customer's ability to effectively understand features of a potentially disruptive innovation; this will in turn invalidate the corporate entrepreneur's evaluations of new opportunities. Whilst we acknowledge the limitations of our experimental design, we believe that we have produced clear evidence to show that these different systems can elicit different and even detrimental responses from customers in the face of potentially disruptive innovation. We hope that our experimental method, findings and analyses will inspire scholars to reconsider the importance of physical prototyping techniques and allow corporate entrepreneurs to identify more disruptive potential from of their opportunity evaluation processes.

NOTES

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[2] Whist market disruption can also be caused by natural and man-made disasters and significant regulatory

change, the remit of this paper is focuses on disruptive innovations forged by profit seeking firms.
[3] We adopt the term 'product' throughout this paper in reference to all tangible and intangible customer offerings.
[4] The term 'power-users' (Nielsen, 1997) is adopted from the computer industry in reference to those who can utilize advanced functions which are usually outside the reach of normal users due to the complexity and advanced knowledge required to perform these tasks. Power users are often the first customers of blue-sky breakthroughs. Microsoft has a "Power Users Group" on Windows 2000 and its later operating systems; they are allowed more permissions than a normal restricted user (http://support.microsoft.com/kb/825069).

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