Voices from the Field:
How Exceptional Electronic Industrial Innovators Innovate

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Abstract:

This exploratory research uses in-depth qualitative interviews to investigate how eleven exceptional innovators in the electronics industry initiated, created and commercialized radical innovations in their firms. From the data, six themes emerge as to how they innovate. They have specific personality characteristics that support creative behavior, supplemented by a business orientation and somewhat idealistic attitude. They prepare for innovation by studying deeply, especially within technology topics, and also broadly, across technology, business and markets. They are motivated both intrinsically and through additional external factors. People communicating what problems are urgent and important to them to be solved produce external motivation to the innovator, who is then intrinsically motivated to create products that solve these people's problems. These exceptional innovators are organizationally savvy and both understand and participate in the politics necessary to gain acceptance of and resources for their project. And finally, they use an innovation process that emphasizes the upfront aspects of finding interesting problems, planning first before executing, understanding customer needs in great detail, to allow them to generate insights into how to solve those problems profitably for the firm. Finally, they actively disseminate knowledge and acceptance of the innovation post-invention.

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INTRODUCTION

New product development is the lifeblood of high technology companies, critical to their ongoing growth. The more radically innovative new products are, while still solving critical customer problems, the more likely these new products are to succeed in the market (Cooper 1984). Additionally, the more radically innovative products are, the more differentiated from competitors' products they are likely to be. Thus, developing radical innovations is critical to firm renewal and long term competitive advantage (Ayers 2005; Raynor and Christensen 2003; Reid and de Brentani 2004).

Some breakthrough products result from formal technology development programs, which are set up with goals specifically to achieve radical innovation. The Radical Innovation Project at Renssalaer Polytechnical Institute (RPI) has studied twelve of these projects longitudinally over ten years (Liefer at al. 2000). Their research broadly investigates how radical innovations develop at firms over time, with the unit of analysis and focus being the project.

Other radical innovations are found serendipitously. For example, Roy Plunkett's discovery of teflon (polytetrafluoroethylene) at Du Pont's Jackson Laboratory in Wilmington, Delaware was serendipity (Plunkett 1964). He was actually trying to find a new synthesis pathway for Freon, a chemical used in refrigerants, using tetrafluoroethylene as a raw material. At that point in time, chemists "knew" the compound could not polymerize. However, it inadvertently polymerized on Plunkett, revolutionizing non-stick coatings and waterproof outdoor clothing. 3M's Post-It Notes® also resulted from the serendipitous insight into an unexpected application for another chemical mistake – a glue that did not stick well. Other examples of serendipitous breakthrough developments can be found in Robinson and Stern (1998).

Whether planned or serendipitous, breakthrough technology-based innovations are made (and identified) by individuals, albeit frequently in the context of working in an organizational setting. Someone has to do the work that creates the innovation, someone has to have the insight to see its utility, and someone has to demonstrate and sell that utility to the organization. Individuals who create these types of breakthrough projects have been called "hero scientists" (Leifer at al. 2000). These individuals have extensive technical expertise, but simultaneously often "see things that others don't see" in that they can visualize applications for the technology. If a firm could understand better how these exceptional innovators develop and work, they might be able to capitalize on their outputs more effectively.

The creativity literature previously has used case study approaches to investigate how highly creative individuals develop and create. In one of the most comprehensive studies, Gardner (1993) developed a framework of consistent patterns creators used based on in-depth studies of seven highly creative individuals, each one exemplifying at least one of the seven intelligences: Sigmund Freud (interpersonal); Albert Einstein (logical-mathematical); Pablo Picasso (spatial); Igor Stravinsky (musical); T.S. Eliot (linguistic); Martha Graham (bodily-kinesthetic); and Mahatma Gandhi (interpersonal). The outcome of this study was a framework in the form of a description of “E.C.,” the “Exemplary Creator,” including aspects of personality, how they developed, how they worked, and how they related to the context of the domains in which they worked. Gardner found that about a decade of immersion into their domain was required before a breakthrough could be made and that during the work associated with the breakthrough, the creators became isolated and marginalized from their peers, creating alone.

While representing very different domains of creativity, allowing some generalizations to be made, the sample has several characteristics that may limit the utility of the results for today’s firms seeking breakthrough products. First, these individuals all created at a particular point in history – the early 1900’s. What was considered creative at one point in time may not still be considered creative if developed at a different point in time, as the domains of knowledge are ever-expanding and what is accepted as “new” by the field of practitioners is relative to what already exists in the domain (Feldman et al. 1994). Certainly, what is known today and considered creative today in these domains differs from what was known and creative over 50 years ago.

The most limiting element of the sample, however, is that each of these creators created as an individual. None of them worked in an organization where the creation had to be accepted and moved through the implementation process in order for it to be a success. Thus, although it describes some aspects of these creators’ relationships with those around them, the framework does not contain any description associated with organizational aspects of innovation.

In a manner similar to Gardner’s (1993) study, the research reported here investigates a set of “hero scientists,” in the domain of the electronics industry in the context of the latter half of the 20th century – individuals who have been responsible for creating breakthrough electronic technologies. Rather than focusing on the radical innovation itself, or using the project as the unit of analysis, we investigated how individuals work in mature firms and create these types of radical innovations. The unit of analysis is the exceptional industrial innovator. This article analyzes and reports on in-depth qualitative interviews with eleven of the 58 inductees into *Electronic Design* magazine’s Engineering Hall of Fame for 2002. These exceptional industrial inventors include Guglielmo Marconi, the inventor of the radio, and Thomas Alva Edison, as well as more contemporary (and still living) individuals, including Jack Kilby (recently deceased, but alive at the time the interviews were conducted), inventor of the integrated circuit, Vincent Cerf, creator of the TCP-IP protocol, and Charles House, "father of the logic analyzer." Using open-ended questions, interviewees were asked in great detail both about how they worked toward their invention, but also about peripheral aspects of their work lives and development as technical inventors. The data were content analyzed to search for themes using a grounded theory approach. The result is an in-depth framework describing a theory about how some innovators in organizations approach and execute exceptional innovation.

The next section reviews the literature underpinning this research. The section after that introduces the methodology used in gathering and analyzing the data. The framework describing how exceptional inventors work is presented next with supporting data from the interviews. A discussion of implications follows. Finally, the manuscript ends with future research directions.

LITERATURE REVIEW

This section first summarizes some of the research in new product development and then in creativity, finding a disconnect between the two literatures.

New Product Development and Radical Innovation

Much of the product development research in the last 15-20 years has taken the perspective that NPD could be managed like any other (complex) process of the firm. The underlying assumption is that standard methods and protocols could be put into place and individuals and teams could follow the process to commercialize repeatably a stream of successful new products. One predominant purpose has been to develop methods and mechanisms that eliminate from product development the dependence upon just one individual's capabilities. Researchers have striven to develop institutionally supported frameworks of procedures and methods that allow any product development team to take an idea from concept through commercialization. That is, the field has worked to change the "art" of individual-based product development to the "science" or process of product development (Griffin 1997).

Many firms have implemented formal new product development processes such as Stage-Gate (Cooper 1990), concurrent engineering (Swink et al 1996), cross-functional teams (Griffin 1997), and a number of new market research (Griffin and Hauser 1993), engineering design and analysis and manufacturing design methodologies (Griffin 1997) with success in improving new product development. However, research on best practices in NPD (Griffin 1997) has not found one best way or set of procedures for developing new products. This research suggests that measuring success, having specific expectations for success levels and innovation-specific strategies, and using formal processes, cross-functional teams, team recognition, multiple qualitative market research methods, and multiple engineering analysis techniques all are more likely to occur in the best firms than in the average firm. However, none of these actions is either necessary or sufficient to becoming a best practice firm (Griffin 1997). Thus, even though formal processes are now in widespread use for NPD, facilitation capabilities are still required for innovation success.

It is important to note, however, that the process view of NPD and research on NPD processes starts after invention, or after the creative idea has been generated and fleshed out into a concrete concept. These formal processes assume that a concept is already in existence (Griffin 1997). This time before there is a well-formed concept to investigate has been termed the “Fuzzy Front End,” or FFE (Smith and Reinertsen 1992). The FFE is the messy “getting started” period of product development, when the product concept is still very fuzzy. It precedes the more formal product development process, and is where creative ideas are generated, customer needs are understood and needs are creatively translated to technical possibilities (Belliveau et al 2002). Over the last decade since Smith and Reinertsen (1992) coined this term, several researchers have investigated the FFE, including Khurana and Rosenthal (1997), who studied how 11 companies handle the FFE. However, they, like most of the NPD research on the FFE, focused on rationalizing the chaos, on creating a process for the messy part of NPD before the “real” process of physical development begins, rather than focusing on how organizations can foster creative FFE development leading to radical innovations and breakthrough products.

The one exception to trying to create order out of chaos in terms of research in this area, as indicated in the Introduction, is the Radical Innovation Project at RPI (cf Leifer et al. 2000; O’Connor et al. 2002; O’Connor and Rice 2001, O’Connor and Veryzer 2001, Rice et al. 2001; 2002). Each of the projects in this research originated out of R&D, starting from a technology push objective. They were initiated explicitly to create a radical innovation. The Radical Innovation Project’s purpose is to glean an understanding of how to manage better through the chaos by obtaining a very rich description of a small sample of radical innovation projects, following them longitudinally. The goal is not necessarily to create a process to manage the FFE, but to provide systematic insight into the twists and turns that these sorts of projects encounter and thereby suggestions for how to expect and react successfully to these difficulties as they are encountered.

While the participants in the RPI study generally do not employ a formal, highly structured process for managing discontinuous NPD efforts, they generally follow consistent, logical processes, and these processes differ significantly from incremental NPD processes (Veryzer 1998). These processes are more exploratory and less customer driven than the typical, incremental NPD process. The discontinuous NPD process focuses on formulating a product application for the emerging technologies. These firms developed prototypes at an early stage to aid in formulating a new product application from the emerging technologies. Prototype construction precedes opportunity analysis, assessment of market attractiveness, market research, and financial analysis.

One of the recent findings of this research is the difficulty these projects encounter in trying to create new markets for their technologies (O'Connor and Rice 2005). The first product application generally is selected by a research scientist with little or no business experience. The application selected in turn influences how the technology is further developed as well as the business model and future revenue stream from the technology. The majority of the firms in this research were disappointed with the forecasted revenue streams from the initial technology application selected by the research scientist. In some cases, disappointment because their forecasts did not meet management's high expectations, given the time and money invested in the radical innovation, resulted in business development individuals being removed from the project and even fired,.

Radical innovation is risky. The longitudinal RPI research followed both successes and failures, finding that one-third of their initial sample were killed before launch or were unsuccessful in the marketplace. Some have come to market, and others are ongoing. It finds that one of the major difficulties technology-driven radical innovation faces is finding a market application for their technology. As the technologies in the current investigation all represent market application successes, it is hoped that understanding more about them will provide insight into overcoming this problem.

Creativity and Product Development

Creativity and creative people have been studied from a number of perspectives and significant progress has been made along several fronts. However, much of the research has focused on highly creative people in the arts and those who produce individual creative outputs, such as books, music, and paintings. Some of the measures of creativity and personality traits have been applied to various populations, obtaining normative standards. Unfortunately, none of these populations include technical individuals creating in large, mature firms.

Indeed, some of the personality traits applicable to these individual populations may not be appropriate for individuals creating in the context of a firm. For example, the trait that most consistently differentiated the creatively successful artist from those who gave up a creative career is cyclothymia, or a cold and aloof demeanor (Csikszenthihalyi et al. 1984). As innovation in firms requires effort from multiple individuals across multiple functional groups, someone with a cold and aloof demeanor is not as likely to be as successful as someone who is warmer in demeanor. The prevailing thought on studying traits and characteristics is that overarching personality traits are unlikely to be found across domains and fields and that individual-level traits associated with creativity must be studied in the context of a particular domain (Csikszentmihalyi 1994).

A few creativity researchers have investigated creativity in firms. For some studies the unit of analysis was the project, with the dependent variable the level of project creativity (Amabile 1997). In other studies, the unit of analysis was the individual, with individual creativity level at a point in time the dependent variable (Amabile et al 2002). This research stream has demonstrated support for Amabile's componential theory of creativity (Figure 1), which postulates that creativity is a result of skills in the task domain, creative thinking skills, and intrinsic motivation to do the task. Amabile's research further suggests that while intrinsic motivation is highly related to creativity, and extrinsic motivation such as explicit rewards and incentives for performance are negatively related with creativity, synergies between intrinsic and some extrinsic motivators in the work place, such as recognition from management for a creative achievement, support individual creativity (Amabile 1998). While the first two skill sets can be taught, motivation must come from within and cannot be externally mandated.

Two proposed models explicitly address whether there are links between creativity and project-based innovation, in organizational contexts, and thus, how NPD success and creativity may be linked. Neither has been tested empirically. These are presented in Figures 2 and 3.

Amabile's (1998) model consists of four aspects. First, achieving individual creativity depends on three components: intrinsic motivation to do the task, skills in the task domain, and skills in creative thinking. Second, individuals (or small teams) go through a structured creative thinking process, where this process closely follows the processes proposed in creative cognition theory for how individuals think creatively (Smith et al. 1995). Third, organizational innovation is depicted as a structured process, where the process she depicts strongly reflects a standard structure of Stage-Gate™ processes in the NPD literature (Cooper 1990). Finally, her model suggests that there is an organizational componential model of creativity that is necessary to support the overall process of organizational innovation and the individual's willingness to be creative. This organizational componential model is an organizational mirror of the individual componential model. It consists of organizational motivation to innovate, resources in the task domain, and skills in innovation management (which differ from skills in creative thinking). The only input from the individual creativity process to the organizational innovation process is as a task in the "produce ideas" stage of the process. That is, the job of individual creativity is to provide the creative idea that a team will then fully develop through their implementation process into a new product. Her article concludes that the skills and organizational environment necessary for creative idea generation are very different than the skills and environment necessary for successful innovation implementation. Indeed, she suggests that intrinsic motivation is most important in supporting creativity, while extrinsic motivation is most important for supporting innovation implementation. Although her later research has suggested that there are a few particular extrinsic motivators that actually support intrinsic motivation for employees in firms (Amabile 1993), her basic thesis is that most extrinsic motivators are intrinsic demotivators for creativity. Her suggested solution to this dilemma is for managers to provide a "creativity oasis" for individuals and teams during the time(s) they are responsible for generating the ideas needed for new product development. These oases relieve the external motivators and support intrinsic motivators for the individual or small ideation team.

West (2002) recently proposed an integrative model of creativity and innovation implementation in work groups, as depicted in Figure 3. His definition of work groups is broader than just product development teams, including assembly and other types of manufacturing work groups. His basic premise suggests that the ability for a team to be creative differs from its ability to implement innovations, supporting Amabile's long held contention that creativity differs from innovation. A major difference, however, is that his model suggests that there is no link between creativity and innovation implementation, that they are independent of each other. His model, which is based on an extensive review of the literature, actually is much more complex than Amabile's, with many more interactions than are depicted in the figure (but alluded to in the article text). He suggests that a major antecedent to both creativity and innovation implementation is a set of integrating group processes. These integrating processes can be positively enhanced by task characteristics that evoke task orientation. On the other hand, increasing team diversity, which is frequently needed for providing the domain knowledge necessary for NPD, first increases, and then after some optimal point of diversity decreases the ability to integrate across the group. External demands (similar to Amabile's external motivators) similarly have an inverted U-shaped relationship with innovation implementation, although they have a negative relationship to creativity. Innovation needs some external demands, but not too many. His model suggests that an overriding need in achieving effective innovation is the facilitation role – someone needs to coordinate and manage a set of integrating group processes.

This theoretical model is rather controversial, and was commented on and critiqued by 4 other applied psychology researchers in this same issue of Applied Psychology (Nijstad et al 2002; Paulus 2002; Shalley 2002; Tjosvold 2002). Shalley (2002) sums up several issues across the commentators when she suggests that the model is neither parsimonious nor empirically tenable, as several of the major constructs are not conceptually distinct. Additionally, a careful reading of the text reveals that the relationships between many of the constructs are far more complex than indicated in the pictured model. There are many inter-relationships and interdependencies among several of the variables, from the literature cited in the article.

Overall, then, there are 5 major conclusions one can reach from these models of creativity and organizational innovation, and the previous literature on creativity and NPD. First, creativity and innovation implementation are two different processes, requiring two different skill sets. Second, highly creative individuals differ normatively from the general population. Third, the question of the relationship (if there is any) between creativity (organizational or individual) and organizational innovation implementation is complex, with a myriad of personal, organizational and external influences. Whether creativity and innovation are related is an open question. Fourth, as West (2002, page 378) says: "Innovation is dynamic, so we must aspire to construct dynamic models representing how groups both shape and are shaped by their environments and their innovations. Yet, we are still at an early stage of understanding group creativity and innovation." Finally, a linkage between creativity, innovation implementation and product development success in the marketplace has not been uncovered empirically.

Most importantly, what is missing in all of this research is the demonstration of a direct link between individual creativity and successful organizational innovation. The research above all assumes that a more creative organization will be more successful at developing breakthrough new products – that individuals in the more creative firm will be able to produce more radical ideas, and then effectively implement the ideas generated. There is thus a disconnect across the creativity and product development literatures. No link has been demonstrated between an individual's or organization's level of creativity and the firm's ability to innovate, especially to create radical innovations.

This research hopes to start filling this gap in the literature by exploring how a group of exceptional electronics innovators in mature US firms relate that they have been able to be successful in creating radical innovations. The research approach used is similar to Gardner's

(1993), in which a set of acknowledged exceptional innovators is investigated to uncover similarities in backgrounds and actions, proposing these similarities as an initial theory as to how individuals create radical innovations in firms.

METHODOLOGY

Sample

This research was exploratory, using a multiple case methodology (Yin 1994). In 2002, the magazine *Electronic Design* celebrated its 50^{th} year of publication. As part of marking their anniversary, they officially established an Engineering Hall of Fame, inducting 58 individuals representing 50 landmark lifetime achievements. The *Electronic Design* readers determined the honorees through online voting. **www.elecdesign.com/Articles/ArticleID/1416/1416.html** provides the full list of honorees: About half of these individuals (such as Thomas Alva Edison, and John L. von Neumann) are no longer alive and therefore unavailable for investigation except through secondary materials. Eleven of the remaining 34 agreed to be interviewed for this research, a response rate of 32%. Table 1 provides a list of the innovations the respondents spoke about in the interviews.

Our respondents were all male, with at least an undergraduate degree in electrical engineering. Interestingly, all the inventors created their landmark inventions while working in medium to large US firms. They were industrial innovators, not entrepreneurial innovators. Thus, the results of this study may not be applicable to individuals working in start-ups, or those innovating in non-profit organizations such as universities or government facilities.

Research Instrument

Exploratory in-depth telephone interviews were conducted with each innovator. Topics covered in the interview were wide-ranging and included having them recount in great detail the process by which they created their invention, how they worked in the context of the firm, customers, and other individuals. Interviews lasted between 30 and 120 minutes, averaging about 60 minutes.

Analysis

Interviews were recorded and transcribed for analysis. The transcripts were reviewed twice to uncover key themes (Miles and Huberman 1994). This process produced five key themes relating to successfully innovating that were salient across all eleven respondents. Even though the inventor’s process of inventing was the focus of the interviews, four additional elements emerged in the analysis as being associated with how extraordinary innovators innovate: personality, perspective, preparation, and political ability. The transcripts were then reanalyzed again at a more detailed level, identifying 253 specific statements made by the respondents that were associated with how and why they innovated. Each statement was coded into one of these five key themes. Seven statements did not fit into these five themes, but fell into the category of motivation, creating a sixth theme.

Once all relevant statements from the transcripts were categorized into themes, each theme was then reviewed to identify additional groupings of repeated or related statements. The process theme contained a large number of statements – 152 or 60% of the total. These statements were organized into sub-themes using qualitative cluster analysis, creating six additional sub-themes relating to how they innovated within the process theme: problem-finding, plan then execute, perform your own market research, pursuing insight, playing with others, and post-invention dissemination.

Limitations

As with all research, there are limitations inherent to the research method, which may impact the generalizability of the results. The first limitation is that these innovators all come from the electronics field. In this field, an individual can indeed be primarily responsible for a major innovation. This may not be true, however, in other fields where projects are enormous (complex software applications, for example) and/or require expertise in very disparate technologies, such as mechanical, electrical and software design (aircraft and automobiles, for example). Another concern is that we only interviewed the innovator, who may have a biased view of what actually occurred. A stronger method would have substantiated their memories by interviewing others associated with the project. Other concerns stem from the retrospective nature of the method. Some of the innovations were developed quite some time in the past, and memories can become fuzzy over time. Additionally, at those points in time the use of formalized product development processes was less prevalent than today (Griffin 1997). Thus, it is possible that the ability of “hero scientists” such as these to arise in the corporation today is far lower now than it was when these individuals were creating and commercializing their innovations. Even with these methodological issues, which may limit the generalizability of the research, several interesting results obtain.

RESULTS

This research uses a grounded theory approach to propose a framework for understanding how exceptional innovators innovate. The framework was developed by identifying key themes salient across all respondents, and the relationships between them. Figure 4 visually presents the framework.

The four elements in the middle of the diagram, elements deriving from the individual's past, arise relatively independently of the firm context. These exceptional innovators generally have strong personalities with several distinct characteristics that contribute to how they creatively think and behave. These characteristics are buttressed by the attitudes in their perspective or worldview, which has developed during their maturation to adulthood. Their perspective on life tends to be simultaneously business-oriented and idealistic. Each innovator took specific steps during their formative years and earlier career to prepare themselves for innovating, including acquiring business knowledge in addition to technical depth and breadth. The final element that operates independently of firm context is these innovators' high motivation to create, specifically directed as a drive to create useful products. Externally motivating factors buttress their natural intrinsic motivation to solve problems.

As the arrows in Figure 4 suggest, these four elements seem to interact in a reinforcing manner. For example, aspects of their personality likely have contributed (or at least reinforce) their idealistic worldview. Their perspective that people should try to improve the world drives them to identify important problems to solve and contributes to their need to create useful products that help people. Their need to create pushes them to make the preparatory effort that enables developing new knowledge and seeing its application. The result seems to be the development of a "whole individual," who can see important problems, has the personality to take them on and put the effort required into solving them, and has the knowledge underpinning to actually make a useful contribution to the area.

The two elements in the outer rings of Figure 4 are associated with how these inventors are successful in the context of the firm. They represent how they operate in the present. First, these extraordinary innovators understand and are good at the political processes of gaining project acceptance and support. This political understanding is what enables these innovators to transfer interesting ideas and creative concepts into the more implementational innovation process. Second, these individuals have constructed distinct processes that enable invention of important products. Furthermore, these processes look quite different from the typical Stage-Gate™ process in several ways (Cooper 1990), with a focus on steps that both precede and extend beyond the traditional product development process boundaries.

Personality

While the focus of the interviews was on the processes they used as innovators, comments and elements of personality arose spontaneously. Personality, the way a person is hard-wired, is relatively difficult to change. It generally coalesces long before an individual enters the work force. Interestingly, as a group these individuals were self-aware. As one said:

“It is essential to get to know yourself in terms of the way you fool yourself, when you are playing games with yourself, when you are falling prey to the very humanness in you” that will get in the way of solving the problems you want to solve. They also were articulate. Interviews that were expected to last less than an hour frequently lasted almost double that time.

In general, these innovators are positivist in nature, with confidence and self-esteem. Granted, confidence and self-esteem might be expected, as they already have been deemed successful by an independent assessment body. However, the sense from the interviews was that they always were confident that they could solve the problems they undertook – even when those problems had existed for a long time, with others being unsuccessful at solving them.

As expected, these individuals are innately curious (“well, maybe I came out of the womb more curious”) and fascinated with technology. These traits lead them to investigate technologies and topics far afield of current assignments. One innovator “got to wondering, ‘well, I don’t know how a phone works.’…so I got a book on how the phone works.” Understanding how a phone works had nothing to do with the logic devices he was currently working on in his job, he just wanted to know how the technology worked. Importantly, they are systems thinkers, thinking holistically about problems. For example, one innovator involved in creating a new platform of computers targeted to engineering users knew that the platform had to be compatible with a particular brand of computers, and that meant that the Fortran code they were developing for the new machine had to be compatible with the bugs embedded in the operating systems of the other brand of computer.

These individuals have a high tolerance for ambiguity, they want to be challenged and accept the risks of undertaking difficult challenges. At the same time, nearly all indicated a need to be patient and willing to persevere in solving these very difficult challenges – “I remember tackling this problem day after day.” They are inherently “finishers,” being unwilling to give up on a problem until they have solved it.

One unexpected characteristic of these innovators is the positive affect many of them spoke of and with. In some, this affect was expressed as a passion for what they were doing. Others expressed that “what we were doing was a lot of fun.” These innovators are emotional.

Add to the above characteristics an action-orientation, and it is clear that their personality sets the stage for being able to undertake and solve difficult problems.

Perspective

As with personality, a number of specific perspectives, or strongly held attitudes, of these innovators also came out in our interviews. The first and foremost of these attitudes, explicitly voiced by nearly all the innovators, is a belief that technology and new products must be salable and able to make profits. Technology is a means to an end, which is to keep the business self-sustainable through creating profits. Although they are fundamentally strong technologists, they are strongly business-oriented.

They also understood that failure is likely when you are undertaking big problems, and they are accepting of that possibility: “These sorts of projects are similar to a .300 batting average in baseball.” While information from their successes is reported here, most spoke of working on failures as well. They have a philosophical recognition and acceptance of failure.

Some also voiced strong attitudes about what is right and wrong. As one innovator put it, he “feels moral responsibility to do the best he can.” Again, even though the focus of the interviews was on activities associated with innovating, attitudes about what is important to them also were voiced.

Preparation

All these innovators undertook specific activities in preparation of being able to innovate. These activities took place across multiple domains, including technical, business and market understanding. In general, their attitude towards preparing is to “study broadly, dig deeply.”

Not unexpectedly, technically these innovators developed great depth in their own sub-field within the electronic domain. However, each also sought out education in peripheral technologies to their own field of core competence. One innovator “brought knowledge from the computer industry to the semiconductor industry: “…you could just see it, that computers were going to be designed by chip manufacturers because they have the core technology.” The result is that they developed great knowledge of multiple technology domains. In pursuing this peripheral knowledge, they also developed an understanding of what others both in their specific fields, as well as generally in the larger field, were doing or attempting with technology.

However, in addition to understanding the technology, these innovators also developed a concrete understanding of the business environment, starting with understanding the business unit context and need to make money. This was done more informally rather than more formally, such as through pursuing an MBA. They developed knowledge of industry trends, but also tracked social trends. Understanding the business environment also includes gaining deep customer knowledge. These innovators have a long history of seeking “unfiltered customer information” by interacting in the marketplace.

The result of this preparation is that these are individuals with far more than just technical understanding. They have created a broad background of knowledge that allows them to join technical insight to customer problems, in the context of understanding that the result must be profitable for the business: “…to me, it is the attitude of learning depth and breadth and relationships and social skills and communication skills." These are long-standing, multi-faceted learners.

Motivation

Virtually every model of creativity includes intrinsic motivation as an element (Amabile 1988; Lovelace 1986). As one innovator said, "I am constantly looking for some source of something to do." Another indicated that "once you are successful, you get to do it again." However, the motivation in these innovators is a directed motivation to create something that solves customer (or potential customer) problems. It consists of two forces. First, customers and firms with urgent and important problems that they desperately need solved are a powerful external force that motivates these exceptional innovators. The presence of real customers who can benefit from their work is highly motivating because it tells the innovators that the work they are doing is important in a concrete way. This force works in concert with the acute intrinsic desire to solve problems that no one else has yet figured out, and the personal satisfaction the innovators derive when they in fact do solve those formerly unsolvable problems. Thus, it is a strong and interacting combination of external and internal forces that motivates these exceptional inventors. What they are driven to create seems to be influenced by their action orientation and their business and moral attitudes. Again, technology for technology's sake is not the goal; solving people's problems is.

Political Capabilities

A major difference between exemplary creators who have been studied in such depth in the arts and those in this research is that these innovators operate in the context of an organization. Each of these innovators has developed the ability to successfully interact within their organizational environment. They know that they must sell their ideas to others, and that they have to work the political issues up (to management), laterally (with others needed to do the job) and externally (with customers and others whose expertise is needed). "You put a product plan together, and it needs to get signed off, OK. Engineering has to sign off, marketing has to sign off, and then the CEO has to sign off." These innovators worked at the middle level of their organizations. They did not have a power position that would allow them to force acceptance of their projects. They depended upon influencing others to gain acceptance and resources. Generally they focused on positive influencing actions, rather than depending upon coercion or other negative mechanisms.

Exceptional innovators frequently use the power of data to manage the politics of innovation. There is nothing as persuasive as having facts: "I got the data from 2,753 cases [of emphysema] over a decade. I had 17 variables and I analyzed them all and came up with remarkably interesting findings…it was validated in 2000 that I nailed a causal understanding of emphysema." The findings for this study were used in setting air pollution standards in Colorado. While outside the innovator's job description, his reliance on data in this inquiry is typical of the importance of factual analysis to the innovators in general.

A number of innovators created novel approaches to managing the political situation. One innovator faced with a management unsupportive of his innovation went to customers, describing the product to them and telling them what it would allow them to do. When customer CEO's began calling his CEO demanding to know when the product would be available, support for finishing the innovation's development materialized. Eventually, sales of this device amounted to more than $ 300 million a year. Another innovator developed and gave a 3-day, hands-on seminar on integrated circuit design to his organization's top managers to familiarize them with the new technology being proposed and its potential applications in designing better circuits. By developing an understanding of the technology's potential in management, resources flowed more freely to the area. Others found bosses who were adept at supporting them and shielding them from outside intrusions, and allowed these managers to manage the politics of the situation – sometimes for many, many years. As one innovator related: "[My boss] would sort of let me go off and do anything that was reasonably crazy. And, I could work on three crazy projects as well as three projects I was supposed to work on…. He agreed that was a good way to work." In return, "I tried to get my boss involved by giving him a progress report every week or two."

Process

The process used by these innovators has two unique aspects compared to the processes depicted in the product development literature. First, their process is more far-reaching than the typical product development process, with more of an emphasis on actions both prior to concept development (Table 2) and post-commercialization. The executional steps, once the "aha" of invention changes to the execution of implementation, were seldom mentioned. These would seemingly follow the rather well-understood product development process. It was things outside that standard executional process that our innovators dwelled on in the interviews. Six elements that are important to the processes these innovators use became apparent from the interviews, as illustrated in Figure 5.

The typical process for these innovators starts with problem finding. They start from an important problem to some set of customers. These innovators spend a long time planning, and only then do they execute. They perform their own, extensive customer research, and they reach out to others as needed throughout the process. These innovators use a number of different mechanisms to pursue insight into solving a problem all along the stages of the process. Finally, they participate actively in dissemination post-invention, helping to push the product's diffusion and use.

The second unique aspect is that the process is highly dynamic across domains, with the innovator iterating across the customer, technology and market through the entire process (Figure 6). This is especially true in the problem-finding and planning stages and is instrumental in pursuing insight. In the problem-finding stage, the innovator will start from some identified customer problem, as related in the motivation section. Then, he will go into the technology domains and work to obtain a very broad understanding of why this is a problem and why it hasn't been solved before, iterating back and forth between technology and customer as needed to obtain a full joint understanding. At various points, this information will be taken back to the broader market more generally and checked for validity. When pursuing insight, the technique is "make a little technical progress, check its viability to customers and in the general market." Thus, while the six different aspects of Figure 5 are discussed below in a linear fashion, there is nearly continuous interplay between obtaining customer information and feedback and seeking the right technical solution, with periodic forays into the broader market to check for validity.

Problem Finding

These exceptional innovators start by looking for an interesting problem to solve. When you ask them how they got started on this innovation, the response is invariably of the form, "well, there was this problem with being able to…" In their terms, a problem is validated as being interesting because someone else (a potential customer) also sees and voiced the value in its being solved. Getting to understanding that an issue is an interesting problem requires interacting repeated with customers to validate the utility of the problem. They proactively look for opportunities in areas in which they are deeply interested, and start from domains in which they have prepared extensively and have deep knowledge. Importantly, they think about the commercial potential of an opportunity right at the outset as a criterion for whether an opportunity is interesting or not. They believe that "in order to make a company successful, you have to still have a product that people really need." They look to find holes in the environment others have deemed as "too difficult to solve," but which industry or market trends or customer knowledge suggested would be commercially interesting. Two common themes in identifying interesting problems were 1) fixing problems with how something currently works and 2) working to significantly simplify complex technology. Nearly half the innovators explicitly indicated that their goal was "trying to make something complex simpler." One related that his job was “figuring out how to take the complexity out of the hands of the power supply designer, by incorporating it into a control circuit that we could integrate as a single chip.” Another innovator noted “when you come across an area where your customer, or your customer to be looks like they are saying, this is too difficult to do, that is a license for you to go into business.”

Plan, Then Execute

In the words of one innovator, the “single biggest mistake technologists make is to just take off.” Another suggested that the “single biggest problem in NPD is figuring out what you are supposed to be doing.” Thus these innovators “first define the problem and make sure it’s defined correctly.”

Generally, after finding an apparently interesting problem, they spent a great deal of effort in problem definition, “spending significant time planning and understanding peripheral technology, base technologies, and customer needs in detail.” Often times the problem they set out to solve is not exactly what it first appeared to be, rather the problems the customer voiced were identifiers of a completely different problem. Their approach to a problem differs from previous individuals who may have tackled the problem in that they seek a much broader understanding of a problem and all of the contextual issues associated with it. Generating this broad understanding takes a long time, and again requires significant customer contact. In one project, “probably 6-9 months went by, dealing with all of these upfront issues before the pencil ever hit the paper.” Sometimes those around them become impatient with the apparent lack of progress, and this is thus a key place that the politics of the project must be managed.

Once they felt they fully understood the context, these innovators set a specific goal for the project, and kept the focus on that specific goal, sometimes for quite a long time, until they were able to make inroads. They "started with the overall idea and refined it fully before moving on to the details,” “developing the larger architecture first, then developing the details.”

Finally, and very importantly, a number of them indicated the importance of “using the right technology to solve a problem independent of whether it is the state-of-the-art.” Part of the planning process then, is seeking out the right technolog(ies) that will allow them to solve the problem. As one innovator said: “before I reinvent the wheel, where have I ever seen a circuit that has any or all of these elements that I think are necessary. And that took me pretty far afield.”

Perform Your Own Market Research

“The only valid market survey is a signed purchase order.” On the one hand, these innovators claim that they do not believe in market research. It would appear, however, that they are talking primarily about market research surveys, because, on the other hand, they emphasize the importance of directly interacting extensively with customers, focusing on their problems to obtain a deep understanding of their needs and repeatedly validating with them both the importance of the problem and the progress in creating the solution. Furthermore, they speak of the need to "better understand the 'whole picture' of performance needs." Many of the innovators understood that customers frequently are not able to articulate their needs clearly, and felt it was their job to help the customers understand their own needs and articulate them – especially the "system of customer needs and interdependencies." They "ask 'why' when questioning customers to get to underlying problems." "So, very often what the guy says that he wants may not reflect necessarily, ultimately, what he needs and what he values…That is not because he's not telling the truth; it is because he is lost and wandering the desert as you are sometimes." These innovators learn to "listen with an open ear," and not one just tuned to information supporting a preconceived notion of customer needs, but rather to really understand the problem at hand.

Interaction with customers occurs not just at the outset of the project, but continues throughout the entire development cycle. Specifications are tentatively developed and then customers are probed to determine whether appropriate trade-offs in performance and feature sets have been made. They will develop specification sheets, working and non-working prototypes, and will demo the products repeatedly to obtain feedback across the development phases. They seek new ways to interact with customers.

Playing with Others Throughout the Process

These innovators are highly connected to others both inside and outside of their firm and technology domains due to their preparation for innovating. While they may start alone on the project in the definitional phase, these innovators will reach out to whomever is appropriate to get what they need during the development process. They will seek out those with complementary skills, including domain skills, such as in a peripheral technology, and functional skills, like marketing, and tap into their knowledge. They also will build the cross-functional team necessary for development. "I got very involved with the main design engineer who was laying out the circuit, I got involved with the main process guy who was hand carrying the wafers through the fab. And, I got really involved with the salesmen who were out and around the world promoting this new product…. And then I would come back and tell the troops how the reception was and get them fired up to deliver this product." Some indicated that they played multiple roles throughout the process – doer, implementor, project leader, coach, mentor, facilitator. "There is a lot of personal interaction involved to persuade the various support groups in the company to play together as a team on this new product." They play the role they need to play to get the product developed.

Pursuing Insight Throughout the Process

While a number of innovators made statements like “there is no one way to do this,” the interviews revealed a number of cues as to how they pursue bringing new insights into solving difficult problems. The first key is to make no assumptions about the problem in the planning stage. While they will start by reviewing past (failed) technical approaches to solving the problem, they “ask a lot of ‘why’ questions, rather than ‘how’” questions. They then proactively work to change their underlying logic processes from those that were used to try and address a problem previously. As part of this process they look under the surface of the stated symptoms and issues for the real problems. They soak up and value information from as many sources as possible.

Some innovators will prepare hypotheses about what approaches might work to solve a problem and then test them. They try things multiple ways and iterate. Even though these innovators said they try to anticipate things that might go wrong, each of these projects stalled at some point in development, with the innovator having no idea how to proceed forward. One innovator used an analogy from sailing: “You lose all control of the sailboat when you are not moving. So, very often in a project, when things really get [crappy], and you are losing your confidence, you are flat on the floor, you have to get the boat moving. It doesn’t make any difference what direction you are going; just get the momentum, any direction. And, it sounds crazy, but very often it works.” Another suggested that, “when stalled, restart from bits that work, play with chunks that you understand and that work – then seek other bits to add to them.” Perseverance is key to ultimately achieving insight.

Very importantly, these innovators do not suffer from the “not invented here” syndrome. They will repurpose technologies previously used for solving other problems when they can avoid having to invent new technologies. In one case an innovator “backed up and used circuit techniques that were not state of the art, but were compatible with the process and were adequate for what we were trying to accomplish.”

As one innovator remarked “There was this floundering process when you are dealing with a problem that I do not believe should be short circuited.” According to them, insight frequently arises out of intuition for what will work from simultaneously having both deep understanding with a simultaneous breadth of understanding. While their intuition is based on their core deep technical understanding of one area, it is supported by learning peripheral technologies, which they can then combine into new configurations. Ultimately, the process of reaching insight is inefficient and time consuming, in part because they consciously bring in new approaches from peripheral technologies and knowledge domains.

Post-Invention Dissemination

The majority of these innovators spoke of the importance of helping disseminate information of the innovation post-invention for two major purposes. First, the innovators are directly involved with generating customer acceptance of the innovation. Second, they are simultaneously collecting additional customer problem and opportunity information to help improve the next generation product, which already may be planned or even in development. Three forms of dissemination activities are important, as indicated below.

"I remember, at that time, really becoming a zealot, a person who is just really involved with selling the product," said one innovator. Working with customers directly to promote the use of the innovation is necessary, particularly when its use will require changes in behavior or changes in designs of other interfacing systems. For example, integrated circuits, while providing vast benefits, required redesigning electronic devices already commercialized to take advantage of those benefits. Another innovator indicated that, for his innovation "Of course, there was no market for it because nobody had anything like this before. So, we had to sort of cook up our own market… So we went off and we found some customers." Because they had solved a real problem that customers had indicated they had, these innovators knew that a market could in fact be developed.

These exceptional innovators also wrote technical papers and spoke at technical conferences to help disseminate new devices and the technologies underlying them. One innovator got his salesmen to set up seminars at customers for him: "You do your pitch and try to get the engineers to light up. And see the concept and see how it will make their jobs easier."

Finally, in some extreme cases, they prepared university curricula, and even donated supporting equipment, for teaching the new technologies and how to design in new paradigms to further disseminate general acceptance in the field. These actions were directed at speeding the rate of diffusion of the innovation, and thereby also speeding the revenue stream to the firm.

Process Summary

From the recitations on how they achieved exceptional innovation, these individuals focused first on finding commercially interesting problems that were important to someone to be solved, defining them completely and understanding the scope and details of the problems in depth, including the full set of customer needs. The amount of up-front time and planning spent was significant. The cross-functional preparation they already had undertaken is augmented with additional new learning as needed for this project. While not able to fully describe how the “ah-ha” of insight was explicitly achieved, they undertook specific activities that would increase the probability of achieving novel insight. They change their role in the process as appropriate, exhibiting role flexibility. Finally, they will not move on to something else once the product is launched, but continue to work to gain acceptance in the marketplace.

Overall, the parts of the processes they focused on in our discussions were those associated with enabling them to achieve creative outputs, rather than those associated with the implementation of the innovation in the more formal product development process. It is clear from their comments on the need to play many roles throughout the product development process that they were involved in that part of the process. However, their focus was on successfully maneuvering through the fuzzy front end, and then, politically selling the output of their front end efforts into the more established product development process, where more routine is in place. Once the project hits the formal process, it seems to be unstoppable, so the focus is on what to do and how to get it there.

DISCUSSION AND FUTURE RESEARCH

This research provides insight into the link between creativity and innovation implementation for radical innovations successful in the market place. This research suggests that exceptional innovators with the potential to create and implement radical new products exist in at least some mature firms. They embody skills in creativity as well as in innovation implementation. Even if they do not innovate completely independently, they are seen as being primarily responsible for the success of the innovation – by independent outsiders – and are associated with the creative, implementation, and even post-implementation process phases.

Because we did not interview a comparable sample of average or moderately successful innovators, we cannot describe specific ways in which this sample of individuals differs from the average technologist. However, as Gardner (1993) did, we can offer a profile that generally describes these types of individuals. These exceptional innovators are intrinsically driven and passionate and rather idealistic about solving problems for real customers while simultaneously creating a profit for the firm. While many aspects of their personality are similar to those found in individually creative people, one major difference is that, likely because depend upon the cooperation of others to complete commercialization, they do not possess cyclothymia, or a cold and aloof demeanor (Csikszenthihalyi et al. 1984). Although all started as very capable technologists, they have each broadened their backgrounds to include significant customer, market, and business knowledge. From our interviews, they do not just operate within the boundaries of the firm’s formal product development process, but emphasize activities in the fuzzy front end, prior to the usual start of product development processes. They have created a process that seems capable of generating radical, novel concepts that people need, and thus for which markets can be created. They start from problems, work to understand them deeply first-hand, take specific creative insight-generating actions throughout the process, and exhibit role flexibility throughout the process. They understand the political realities of their firm, and have developed the capability to manage the political landscape, most frequently using positive influencing mechanisms, obtaining acceptance and support for their projects. They have simultaneously mastered the skills of creativity, political management, and implementation.

A major result from this research is that there is much more to understanding how these extraordinary innovators operate than just motivation, domain knowledge and creativity tools as suggested by Amabile's (1988) componential model of creativity, although all of these elements are in the model developed from studying these innovators. These individuals' preparation provides deep domain knowledge, and all are intrinsically motivated. Several of the process skills are creativity skills, such as those used in problem-finding and insight generation. However, even within these categories of the componential model, there are nuances of difference.

First, in contrast to some of Amabile's findings (Amabile 1998; Amabile et al. 2002), these innovators are, at least in part, strongly motivated by extrinsic factors. They are motivated not just to create for their own utility or pleasure, but to create to solve problems that other people say are important to them. This motivation may arise from their somewhat idealistic perspective – they want to help others. Thus, in addition to management recognition as an extrinsic motivator, which Amabile's research identified, recognition by customers external to the firm supports intrinsic motivation, at least for these exceptional innovators.

Second, their preparation combines technical, business, market and even social components. Because of the organizational location of their innovation, they cannot afford to be aloof and cold as Csikszenthihalyi et al. (1984) found separated successful from unsuccessful artists or isolated from their peers and marginalized, as Gardner's exemplary creators were (Gardner 1993). In order to be successful, these must obtain political (social) skills.

Finally, the model of organizational innovation developed here differs significantly from that proposed either by West (2002) or Amabile (1988). Most importantly, this model is individually led, rather than being team-driven, as the two other models are structured. Additionally, both models neglect to take into account the political nature of the development process, except perhaps implicitly, nested within other dimensions of the model. The exceptional innovators understand that acquiring these skills and managing the political process is crucial to their success in the organization. The model of the process these innovators use stresses the up-front steps, but also the post-invention dissemination that is necessary. This element is neglected in virtually all models of innovation and product development.

Our research shows some differences from past research on personality differences between more and less creative scientists. As has been found consistently for more creative scientists, our exceptional innovators seem to be open to experience, flexible of thought, self-confident and have drive, ambition, and a need for achievement (Feist 1999).[1] Where our individuals would appear to differ significantly is that they do not appear to be arrogant, hostile or introverted, as studies of more creative scientists consistently have found them to be. If anything, our innovators are just the opposite – they were engaging during the interviews and well networked into their organizations. A major difference between the scientists that have been studied in the past and our innovators, is that the scientists were typically in academia, not operating in the context of a firm. Our firm-based innovators are dependent upon the good will of the people around them to help them move the project through the various functions of the firm and into the marketplace. Thus, we would not expect that they could be hostile or arrogant and be successful.

One interesting aspect of these innovators has to do with how they view risk. First, none of these innovators was an entrepreneur. Each innovated in the context of a medium to large firm and virtually all of them have remained with established firms throughout their career. Had these innovators created their innovations as entrepreneurs, they likely would have had a far higher personal financial return.[2] However, they preferred the financial and resource support and stability of an established firm. This suggests a type of risk aversion. This also suggests that there may well continue to be a place for radical innovation in large established organizations. Firms need to figure out how to take advantage of individuals who seem to be driven to undertake radical innovation in the context of an established organization.

Clearly, marketing as a function has failed these innovators, as shown by their stated lack of belief in marketing research. However, almost ¼ of the process-related statements they made had to do with obtaining deep and complete understanding of customer problems and needs and interacting with customers throughout the entire development process. As shown in previous research (Griffin and Hauser 1993), these innovators need to understand both the

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[1] Feist (1999) provides lists of a large number of studies reporting on each of these personality differences between more and less creative scientists.

[2] It should be noted that there are other Hall of Fame inductees who innovated as entrepreneurs, including Steven P. Jobs and Steven Wozniak, benefiting significantly. However, our sample did not include any of these individuals.

details and the full set of needs in order to make the technology trade-off decisions crucial to success. New techniques to more effectively and efficiently support their quest for this information need to be developed, including more efficient mechanisms for finding the “right” customers to talk to. Additionally, firms need to ensure that financial support is available as well as sufficient managerial encouragement is present to go into the field.

Understanding that there is both a past and a present dimension that has enabled these individuals to be so innovative is important from a managerial perspective. It suggests that high-potential individuals might be recognizable early in their career, perhaps through a combination of recognized personality traits, innate idealistic perspectives on the world, and strong intrinsic motivation to innovate. Once recognized, the firm might be able to increase the probability that these potential innovators will create exceptional innovations by proactively seeing that they acquire a broad business and both broad and deep technical preparation. With this background and preparation, if the firm could turn them loose on important problems, relevant to their knowledge bases, perhaps the incidences of exceptional innovation could be increased.

This research complements the findings from RPI’s Radical Innovation project in a useful way. Over 10 years of longitudinal research, RPI has followed a dozen radical innovation projects, creating significant new insight into managing radical innovation as a process (Rice et al. 2002; Veryzer 1998), organizing to manage radical innovation (Leifer et al. 2001; Rice et al. 2000), and identifying opportunities (O’Connor and Rice 2001, Rice et al. 2001). Their unit of analysis has been the project, and all of their projects have originated in the R&D labs from a technology push start. At the outset, it was not clear which, if any, of the projects would ultimately be successful. Our research complements their findings because it has a different unit of analysis – the primary innovator, and because all these innovators had successful outcomes. This allows us to take a different perspective on understanding similar phenomena.

A radical innovation project initiated as a technology push seems to proceed much differently than these projects by exceptional innovators. The technology push projects begin without any idea of the application area to which the technology will be applied (O’Connor 2005). The “hero scientists” of the early phases of the project have little or no business or market experience, and the task is pure technology-oriented. It isn’t until later in the project that someone with business experience is brought on board to create the initial business plan. However, forecasts for sales and revenues depend upon the specific application(s) into which the technology will be directed. In these cases it is the scientist who has identified the early application(s), with little or no understanding of the business ramifications of their selected applications. Interestingly, these applications generally are not the “killer apps” that will generate the revenue level the firm wants. However, as the technology development has been directed to achieve those applications, the initial business manager is stuck with them, at least in the short-medium term. Management frequently ends up removing or even firing the initial business manager in a significant number of the projects because of the disconnect between likely revenue streams and management's expectation of future revenue streams.

These exceptional innovators, on the other hand, start from a commercially important problem, not a technology. Even though they are technologists by training, and they make significant technical contributions and breakthroughs, they see technology as a means to an end – and it is the profitable end that is important, not the means. They fully understand that a product has to produce profits and is most likely to do so by solving significant problems for people or firms. Thus, they start their efforts with an application in mind, and one that some set of facts has suggested has the potential to bring in the kind of profits that will be of interest to the firm. Then, they go seek the technology to solve the problem, iterating back and forth across the customer, market and technology domains to validate the importance of the problem and appropriateness of the solution. This would appear to be a very different way to manage the process of radical innovation – one that seemingly operates less in a business vacuum than the technology push approach.

On the one hand, we are not suggesting that exceptional innovators should supplant the firm's formal development processes, or even technology push radical innovation. Using formal processes is associated with higher success from NPD (Griffin 1997). Some technology push projects are successful. On the other hand, perhaps firms can benefit from supporting formal product development programs and simultaneously taking advantage of these exceptionally innovative individuals who seem to want to remain in large firms.

It would appear, however, that in order take advantage of exceptional innovators, the firm may have to manage them differently than those who are innovating within the context of current platforms and product lines, using the formal processes of the firm. Mismanaging them can have detrimental consequences: "…we had a new general manager who said 'engineering will do engineering, they won't think, they will do what marketing tells them to do.' And, I looked at the things marketing told me to do and I said, 'this is not going to work very well because they don't know what the [heck] they are doing.' And, at that time, I quit." Thus, it is important for firms to find (or create) places in the organization that will support and even enable these individual's desire to create and innovate.

Several useful avenues for future research exist. Research grounded in the current situations at firms needs to be undertaken to determine whether the diffusion of more formal product development processes has mitigated the potential of taking advantage of the output of exceptional innovators. Thus, one investigation could delve into whether and how these two mechanisms for innovation, formal processes and exceptional individual innovators, can coexist in firms. Additional research also is needed to refine, define, and understand the specific processes exceptional innovators use, perhaps by investigating other industry contexts. Significant research is needed to explore whether particular personality characteristics are associated with exceptional innovators. The goal would be to use evidence of resident personality characteristics, perspectives (attitudes) and preparation to identify exceptional innovators earlier in their career. Most importantly to firms, future research needs to develop an understanding of how to develop and manage exceptional innovators in the most effective way. This will allow them to take optimal advantage of their abilities. Finally, research needs to investigate the relationship between firm strategy and innovator presence and utility in achieving that strategy.

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Table 1. Industrial Innovation Invention Times

Date	Innovation
1958	Integrated Circuit
1968	Voltage-frequency Converter
1970	Logic Analyzer
Mid-1970's	Pulse-Width Modulation Controller
	"C" Programming Language
	Lasers/Photonics
Early 1980's	Programmable Array Logic
	Mini-Supercomputer
	Internet/TCP/IP Protocol
	Analog to Digital Converter
1990	LCD Display Lamp

Table 2. Elements of Exceptional Innovator's Processes

Process Element	# Statements	% of Total (152)
Problem-Finding	31	20.4%
Plan, then Execute	26	17.1%
Perform Your Own Market Research	37	24.3%
Pursuing Insight	39	25.7%
Playing with Others	11	7.2%
Post-Invention Push	8	5.3%

Figure 1. Amabile's Componential Model of Creativity (adapted from Amabile 1998)

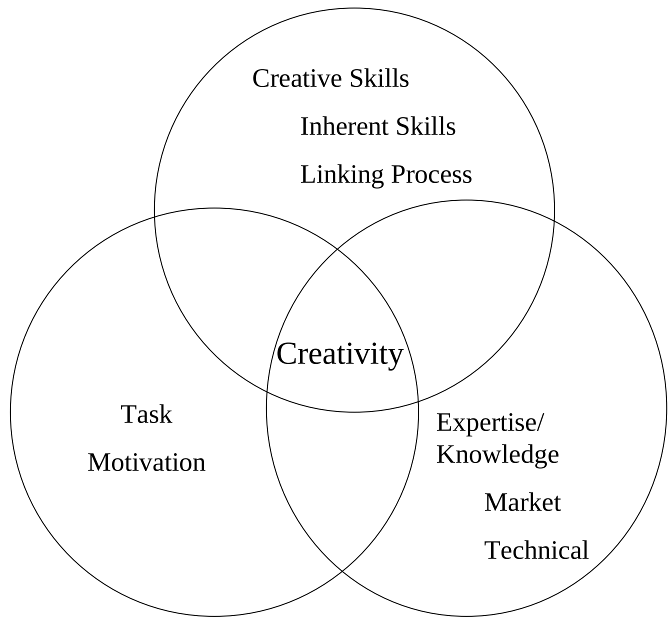

Figure 2. Componential Model of Organizational Innovation
(simplified from Amabile 1988)

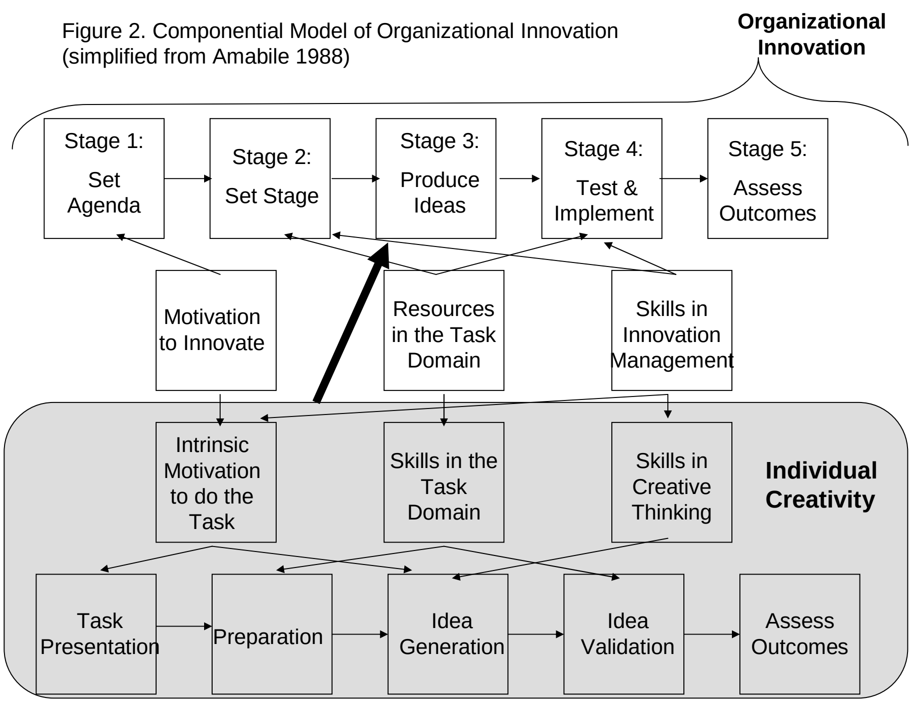

Figure 3. Model of Team Innovation
Source: West 2002

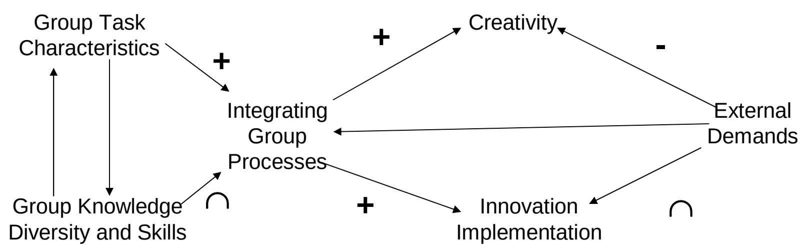

Figure 4. The Six Elements of Extraordinary Electronic Industrial Inventors: MP^5

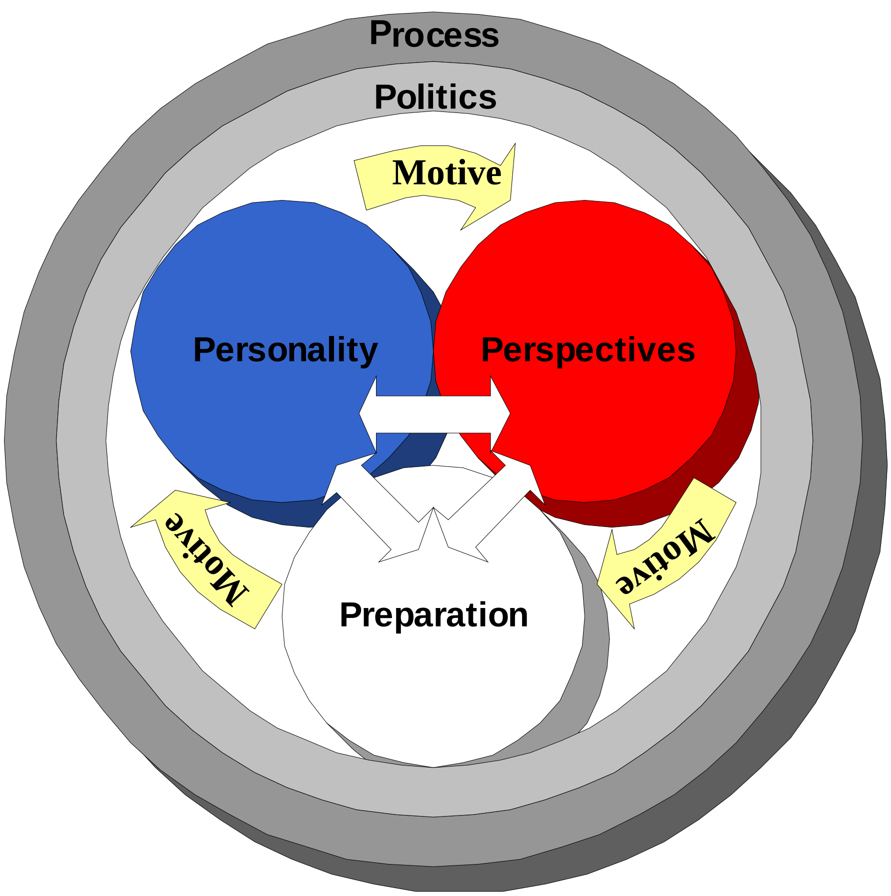

Figure 5. The Process Used by Exceptional Industrial Inventors

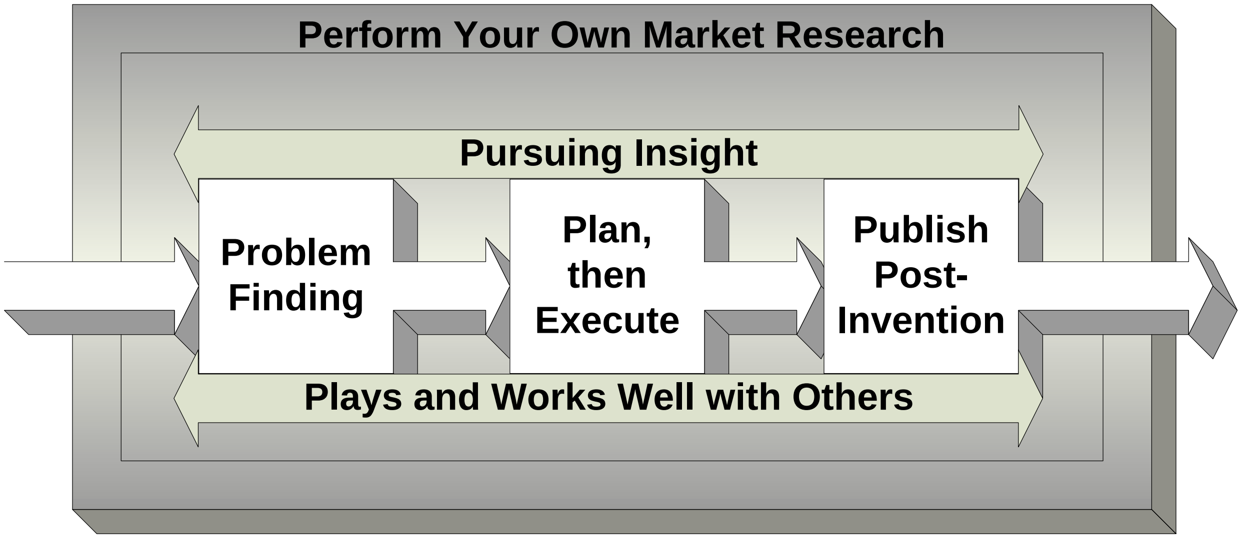

Figure 6. Dynamics of Exceptional Innovators' Processes:

The Convergence of Customer and Technology