Creativity

From Potential to Realization

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7

INVENTORS: THE ORDINARY GENIUS NEXT DOOR

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Psychologists and scholars have been studying the nature of creativity for more than a century. Countless empirical studies have focused on artists, writers, and musicians as the exemplars of the creative. Relatively few scholars have focused on inventors and their creative process. This is curious in light of the profound influence inventors have had on the Western lifestyle and standard of living. Biographies of famous inventors such as Alexander Graham Bell and Henry Ford are plentiful in bookstores and libraries. Psychological studies of inventors, especially those less famous, are harder to come by. It is the entrepreneurs (e.g., Lee Iacocca, Steve Jobs, Dave Packard, and Bill Hewlett) at the helm of inventive companies who have traditionally enjoyed more of the public eye.

Would psychological studies of inventors be useful to our general understanding of creative behavior? Is it possible to have a full understanding of creative people without a portrait of the inventors who have collectively influenced our society? To ponder this question, let's consider the story of how the Internet came to exist. Tim Berners-Lee proposed a global hypertext

The chapter title was inspired by the following two titles: the article on resiliency titled, "Ordinary Magic," by Anne Masten, PhD, (2001), and the book title, *The Millionaire Next Door*, by Stanley and Danko (1996).

project in 1989 to facilitate technical collaboration at CERN, a particle physics laboratory in Geneva, Switzerland. Berners-Lee's project proposal initiated what later became the World Wide Web technology (Berners-Lee, 1999; Wright, 1997). Though Tim Berners-Lee can be credited for creating the initial technology and inspiring its extraordinary development, the World Wide Web and the Internet were built steadily over time through both the independent and collective work of thousands of inventors. We know about the life and work of Tim Lee, but what do we know about the high-tech inventors that brought his vision to reality?

Public interest has begun to shift toward the work of inventors, perhaps spurred by the bull market of the 1990s and the rise in high technology. Inventors are now being celebrated on center stage as the very individuals who have quietly built the technologies fueling a marketplace revolution. For example, the *New Yorker* (MacFarquhar, 1999) and *Fortune* magazine (Stipp, 1999) offered close-up profiles of one MIT trained inventor, David Levy. Hewlett Packard Company adopted "HP Invent" as their central marketing logo ("HP Invent," 1999). Some corporate Web sites now feature photographic stories of their staff inventors and associated innovation successes ("IBM Research News," 2003). The Lemelson-MIT program Web site now features "Inventor of the Week" (2003). As a critical complement to Rossman's (1935, 1964) study of early 19th century inventors, comparative studies of inventors have begun to emerge (see Brown, 1988; Henderson, 2003, 2004; Huber, 1998; Weber & Perkins, 1992).

INVENTION DEFINED

Invention and its ultimate influence on society is a complex interaction among human creativity, the current state of technology and knowledge, and ultimately the needs of the market consumer. The current state of science and technology reflects both incremental and dramatic leaps in human discovery. The variety of terms used to characterize an invention may distract from an accurate understanding of the creativity and market potential of an invention. Pick up a prominent business magazine, and one is sure to encounter terms such as, *create*, *innovate*, *develop*, *discover*, *improve*, and *disrupt* alongside or in place of the term *invent*. This proliferation of terms perhaps reflects the struggle within the English language to capture the nuance of creativity behind technical invention. The crux of the issue is that whereas some inventions leapfrog existing technology (e.g., the light bulb versus the candle lantern), most inventions improve on existing technology (e.g., amoxicillin versus penicillin). Innovation in its purest definition may more accurately refer to technology improvements, yet it is pervasively used in technology circles to characterize products that verifiably alter technology. For simplicity, the term *invention* is used exclusively through this chapter.

There are five critical dimensions that distinguish invention from other forms of creativity: (a) novelty, (b) utility, (c) cost-effectiveness, (d) impact on the marketplace, and (e) the opportunity for patent acquisition. The following broad definition of an invention, therefore, will guide the discussion in this chapter:

> An invention is created through the production of novel ideas, processes, or products that solve a problem, fit a situation, or accomplish a goal in a way that is novel, implementable, useful, and cost-effective and alters or otherwise disrupts an aspect of technology.

This conceptualization was derived from previous definitions offered by prominent scholars in creativity (see Amabile, 1983; Becker, 1994; MacKinnon, 1962; Rossman, 1964; Torrance, 1974; Vosburg & Kaufmann, 1999).

The above definition of invention carves out some important questions about what defines the creativity of inventing work. What does it mean for a product, process, or idea to be novel, implementable, useful, and cost-effective and to alter or disrupt existing technology? How is invention different from other products of creative behavior, such as fine art and sculpture? Do patents define an invention's merit to society?

Novelty

Consider novelty as it relates to fine art versus inventing work. Novelty in a painting or sculpture is an attribute that will catch the eye of art critics and collectors. Similarly, novelty in invention distinguishes a product or process from other existing technology. Novelty in art, however, is an end in itself. That is to say, novelty in art can be both *necessary* and *sufficient* to its function in the world. In the arena of invention, novelty is necessary but rarely sufficient. An invention must not only be novel but it must also "solve a problem, fit a situation, or accomplish a goal," as stated in the above definition. That is, an invention must meet a societal need and be adopted in the marketplace to be deemed successful and relevant. The novelty of artistic expression may define its aesthetic merit to society, whereas the novelty of invention will only partially determine its value to the market consumer.

Utility

The utility of an invention is defined by its implementability, cost-effectiveness, and its match with what is needed in current society. This concept is perhaps best illustrated by the story of one recent invention that has been the subject of much political controversy. Cities struggle with finding efficient ways to manage the transportation needs of the public in the face of road congestion. In response, Dean Kamen, a highly successful modern inventor, introduced the "Segway" to the market in 2002. The Segway is an electric scooter designed for use on sidewalks as an alternative to car commuting. It features a unique gyroscopic technology that facilitates maneuverability at speeds up to 15 miles per hour. However the Segway, which may indeed eventually revolutionize city transportation, has recently encountered some resistance to its implementation. The San Francisco city government, concerned about safety risks to the young, senior, and disabled people walking along sidewalks, recently outlawed the invention (Watercutter, 2003). Whereas novelty has been the Segway's advantage, concerns about its implementability are slowing its market adoption. Note, however, that an invention's utility often evolves well after the initial offering of a novel invention. For example, Henry Ford successfully introduced the Model T years after Nicholas August Otto invented the gas motor engine in 1876 (Bellis, 2003a).

Cost-Effectiveness

Consider inventions designed to keep city sidewalks clean and clear of debris. Many novel inventions out-price the market pocketbook. Consider the "Steamin' Gum Gun" designed to remove unsightly chewing gum from city sidewalks. This invention may be novel and useful yet too costly for many city governments. The "Steamin' Gum Gun" is now priced on the Internet at more than $4,000 per unit. Compare this to the leaf blower, which was and remains a controversial solution to dead leaves on the sidewalk. Despite the associated noise pollution, the leaf blower has succeeded in gaining significant market acceptance perhaps due to the efficiency and cost savings associated with the solution (unit price less than $100).

Impact

How many, how often, and how long people use an invention may indeed signal the novelty, utility, cost-effectiveness, and implementability of the invention. These dimensions will influence the *rate of the adoption* of any given invention. The *impact* of an invention also depends on the degree to which the invention alters and disrupts the way people think, feel, or act in the world. When considering the merit of an invention therefore, it is the resulting change in technology that becomes a central defining feature.

Patents

One last unique feature of inventions, something that has no analogue in art, is the patent award. Fine art may be appraised and insured, but to date paintings and sculptures have not been patented. This may be a distinguishing feature but not always a meaningful one when evaluating the creative merit of an invention. The U.S. Patent and Trademark office began protecting invention to track the development of technology but also to provide financial incentive for continued invention by allowing patentees to collect royalty income from their invention successes.

Although potentially lucrative, many inventors are nevertheless skeptical about the ability of a patent award to reflect accurately the importance of inventions and the expertise of inventors (Henderson, 1999). Inventions vary in technical complexity and in time required for development (i.e., time-to-market). Patent acquisition is expensive, and in practice more influenced by corporate priorities, incentives, and legal support (not to mention the changes in patent law) than novelty or impact on the marketplace. Furthermore, many an invention has been awarded a patent but has not endured well in the marketplace (e.g., 8-track cassettes). Ultimately it is the marketplace rather than the U.S. Federal Patent Office that awards an invention its creative merit.

INVENTORS AND CREATIVITY

The attribute that probably most distinguishes inventors from other creative people is their orientation toward problem solving. Although accidents have inspired many an invention (e.g., Silly Putty, Post-it Notes, the pacemaker, and the microwave), most inventions are deliberate solutions to problems in the current state of technology ("Inventor of the week archive," 1998; "Microwave oven," 2002). The process of inventing new products involves identifying unmet needs in society, zeroing in on the underlying technological conundrums, and then discovering novel solutions; inventors therefore can be deemed expert problem solvers in the physical world.

Problem solving is so central to the process of inventing, that graduate programs in engineering and product design teach the art of problem finding (Adams, 1972; Faste, 1972; MacFarquhar, 1999). Some product design programs require beginning students to create a list of problems in daily life, such as the annoyance of losing keys (Henderson, 2000a). Out of this list, students are then asked to solve a selection of these problems through invention.

Is it not true, one might ask, that artists solve technical problems to create what is in their mind's eye? Nearly all forms of creativity, in fact, involve problem-solving effort. Musicians are challenged by how to create novel sound with traditional instruments, filmmakers with how to create a mood behind a common scene, and writers with how to create a vivid scene in the mind's eye of readers, with mere words on a page. Scholars have found problem finding to be a critical cognitive process (Getz & Lubart, 1999) among all people and central to the process of successful artists. Getzels and Csikszentmihalyi (1976) found that novelty in fine art depended on delay of problem foreclosure by students in their artistic process.

Where the act of problem finding is common to both the artistic and the inventive process, the *motivation* behind problem solving is unique to inventors. Whereas artists solve problems in service of fulfilling a particular vision for their art, inventors solve problems in service of market need. For this reason, an inventor's process of invention will seldom bring notoriety, as is the case in an artist's technique and style (i.e., Seurat's and Lichtenstein's pointillism, Matisse's continuous line, Picasso's cubism, and Magritte's play on what is actually real). Writers have addressed key aspects of the inventing process, such as brainstorming, idea generation, and the management of corporate innovation (Kelley, 2001). The ideas are most commonly discussed in general rather than associated with the personal inventing styles of a particular individual. The point here is that inventors become known for their solutions to the needs of the marketplace (if they become known at all) rather than for the features of their artistic process.

PROFILES OF THE 21ST-CENTURY INVENTOR

Results from two recent interview- and survey-based studies on inventors (Henderson, 2003, 2004) inform the following discussion about the profile of the 21st-century corporate inventor and the underlying psychology of how and why they do the inventing work that they do.

Method of the Studies

Study 1 (Henderson, 2004) was qualitative in design, involving in-depth interviews of four product inventors and two similarly trained noninventing professionals as control based in Silicon Valley, California. These individuals were interviewed in three consecutive individual face-to-face or phone meetings. Three face-to-face focus group meetings were also held. The interviews were guided by semistructured, open-ended questions inquiring about the intrapersonal, interpersonal, environmental, social, and cultural factors that might have influenced the creative achievement of the participants. These inventors were employed at a technology incubator firm and the other inventors work at a start-up company advancing robotics technology.

Study 2 was a one-time, cross-sectional survey of corporate inventors with no control group. From a convenience sample of 1,070 employed inventors, 247 participants completed a 90-question on-line survey requiring a mean time of 20 minutes to complete. This survey evaluated inventor motivation, role identity, inventing skill, and their reports on early formative experiences. The survey's 23% response rate is lower than what would be expected for mail surveys but on par with the lower response rates found in on-line surveys (Dillman, 2000).

Almost all participants (96%) of Study 2 were employed by one of three multinational companies dedicated to the research, design, and creation of new scientific processes and products in the area of consumer products (household, electronic, or mechanical), computer and Internet solutions, and high technology. The other participants were recruited via a graduate engineering alumni e-mail list of a major university. The three participating companies were headquartered in Silicon Valley, California, and had offices worldwide. The size of these development labs ranged from 200 to 450 nonmanagerial individuals making a living by inventing.

Results

Role Identity as an "Inventor"

Individuals doing inventing work hold many different professional titles within the workplace, such as designer, developer, scientist, physicist, technician, and engineer. Because role identity is believed to have a strong influence on motivation (Petkus, 1996), the concept was evaluated in Study 2 using Erickson's concept of psychosocial identity (1968). To accomplish this, survey participants were asked the following two questions (Henderson, 2003) (a) How central is being an inventor to how you perceive yourself? and (b) How central is being an inventor to how others perceive you? The 6-item Likert scale was worded as follows: (a) completely central, (b) very central, (c) somewhat central, (d) not very central, (e) not at all central, and (f) N/A.

The majority (85%) of participants of Study 2 reported that "being an inventor" was "somewhat," "very," or "completely" central to the way they perceived themselves and the way others perceived them. Interestingly, the participating companies varied considerably in how much they promoted "inventor" as a professional identity. Whatever emphasis there was seemed to vary across managers within the organizations, and as expected, there were no significant differences in inventor identity across the recruiting sources of this study. It may be that individual role identity of people doing inventing emerges because of a long series of personal, educational, and professional experiences in different environments much the same as psychosocial identity. Thus, the role identity of "inventor" may have much more to do with an individual's present and historical work activities than it does the corporate job title.

There were no significant differences in role identity across ethnicity and education. There were differences, however, found within gender. The female participants in Study 2 were almost three times less likely to report that being an inventor was "very" or "completely" central to their role identity as an inventor than male participants. At the same time, the male participants were more likely to disclaim completely their inventor identity than their female counterparts. In this case, men in the study were two times more likely than women to report that being an inventor was "not at all" or "not very" central to their role identity.

Demographics of Inventors

Inventors of the Past. In the early 1900s, Rossman sent a psychology survey to successful inventors through the U.S. Patent Office. Through this method, he recruited the participation of 710 inventors. Given the proliferation of invention that began in the early 1900s, the Rossman study (1935, 1964) has offered important baseline information for all future research on inventors. Rossman's 710 participants were all male individuals who had obtained their first patent between the ages of 15–30, with 20,859 patents in total. Nearly two-thirds of the participants (59%) were college-educated individuals and had been awarded an average of 47.3 patents each, holding 95% of the total patents. The inventors without formal education (41%) averaged 3.6 patents per person.

Inventors Today. Since the days of Rossman's study, technology has advanced exponentially as has the technical complexity of inventing work. In this respect, the demand for technically agile and creative minds has spurred the availability of higher education in math, science, and engineering. Perhaps entertainment media have produced the most comical depictions of inventors. Often in movies, cartoons, and in comic books, inventors are characterized as zany eccentrics, like "Doc Brown" played by Christopher Lloyd in the mid-80s movie, *Back to the Future*. The truth is, though, that most inventors are little known and seldom stand out in a crowd (MacFarquhar, 1999; Rogers, 1986; Rossman, 1964). It is clear that the impact of an invention does not necessarily lead to fame. For example, though Vladimir Kosma Zworykin and Philo Farnsworth are credited with inventing the television (Postman, 2003), they may not hold much name recognition among the public. The same phenomenon applies to Jack Kilby and Robert Noyce, who invented the microchip (Bellis, 2003b; Weiss, 1999); it is Intel and other computer companies that have received the fame.

In Study 2, 247 inventors comprised a select sample of older, more experienced, and more highly educated inventors that included women and people of color. Of those participants willing to disclose their gender (96%, $n = 238$), approximately 81% were men and 19% women. Compared with U.S. national statistics on engineers and scientists in 1997, women in this study were slightly underrepresented (National Science Foundation, 1997: 77% men, 23% women). The mean age of participants in this study was 37.6 years (ranging from 19–74 years), with significant differences among men (38.4 years) and women (34.2 years). The average age of the study participants was on par with the national statistics collected in 1997. *Science and Engineering Indicators 2000* reported: "With the exception of new fields such as computer sciences (where 70 percent of degree holders are under age 40), the greatest population density of individuals with S&E [science and engineering] degrees [in science and engineering occupations] occurs between ages 40 and 49" (National Science Board, 2000, p. 22). This same report also explained that, "Because large numbers of women and minorities have entered S&E fields only relatively recently, women and minority men are generally younger and have fewer years of experience" (National Science Board, 2000, p. 10).

In terms of education level, approximately 31% of the participants had PhDs, 31% had Master's degrees, 6% had professional school training, 29% had college degrees, 2% had high school degrees, and 1% declined to answer. The participants together acquired an average of 6 patents each, 1,498 patents in total. Compared to national statistics (National Science Foundation, 1997), the participants in this study were more highly trained than engineers and scientists across the nation in 1997, 28% then holding MAs and 13% holding PhDs.

Of those willing to disclose ethnicity (92%, $n = 227$), 80% were White, 9% were of multi-heritage, 2% Korean, 2% Japanese, and the remaining 7% were Latino, Vietnamese, or "other." There were significant differences in education by ethnicity when grouped as White versus non-White (x^2 (4,225) = 9.52, $p < .05$) but not by gender. The 20% of non-White participants in this study compared favorably in terms of diversity to the 1997 nationwide National Science Foundation statistics, which indicated a presence of 16% non-White engineers and scientists. In this study, proportionally fewer non-White participants had education at the college, professional school, and Master's degree level of training, and proportionally more at the PhD level.

Caution is advised when generalizing the results of this study to inventors as a whole because the data were collected from a convenience sample without control group. Also, the proportion of White male inventors discussed above should by no means diminish the actual impact of women and people of color in the inventing world. Despite the well-known limits on social, political, educational, and economic opportunity available to people of color and to women over history, minorities have had an impact on the world as we now know it through invention. Diverse peoples, including young children, have contributed to the current technological revolution. Appendix 7.1 provides a list of Internet Web sites that discuss how diverse peoples have contributed to our technological progress.

THE PSYCHOLOGY OF THE MODERN INVENTOR

In the preceding sections, we examined invention and the creative properties of invention. We then discussed the role identity of people making a living by inventing in terms of whether or not they perceive themselves and are perceived by others as inventors. Then, we reviewed a snapshot of 21st-century inventors as compared with inventors of the early 1900s. Moving from a descriptive analysis of invention and the people who create them, we now move toward a more fundamental exploration of the internal attributes of inventors. The key question now is, what motivates inventors' creative achievement and how have they developed their interest in and talent and expertise at inventing? To provide context for this question, we start by outlining the overall framework and the measures of Study 2.

Framework

Martin Ford's living systems framework (1992) guided the studies. This framework addressed the psychological foundation for understanding human competence by outlining the internal and external determinants of achievement (see Figure 7.1) Four theoretical models served to elucidate further the components of Ford's framework. For example, the motivational systems theory (Ford, 1992) offered a structure for systematic study of three internal psychological functions that motivate goal-directed activity: *personal goals*, *emotion*, and *personal agency* (also known as self-efficacy). Whereas personal goals and personal agency were adequately addressed by the motivational systems theory, emotion needed further elaboration. Two models of creativity and affect offered by Sandra Russ (1993, 1999) and Melvin Shaw (1989, 1994) helped to expand concepts on the role of emotional arousal in inventing achievement. As a further complement to Ford's framework, *environment* and *skill* were addressed via John Krumboltz's social learning theory of career decision making (1979). The Krumboltz theory focused on how early home and school experiences of inventors might have contributed to later educational and professional endeavor in the inventing world.

Measures for Creative Achievement and Motivational Correlates

Inventing achievement was evaluated, both subjectively and objectively, through the use of five dependent variables. The first three measures involved subjective questions using a Likert scale: (a) place on a hypothesized ladder of recognition, (b) sense of accomplishment, and (c) personal rating of overall success as an inventor. The last two measures were objective using (d) numbers of publications and conference presentations made and (e) numbers of patents, both pending and awarded.

The independent measures were (a) skill, measured by years of inventing experience and level of education; (b) emotion, measured via a Likert scale with questions assessing subjective well-being in one's work life, with the type of work and in the current work situation; and (c) personal agency (also known as self-efficacy), which measured the participants' belief in their ability to invent with a Likert scale. The last two dimensions, personal goals and formative environment, were evaluated through open-ended questions soliciting a short written response.

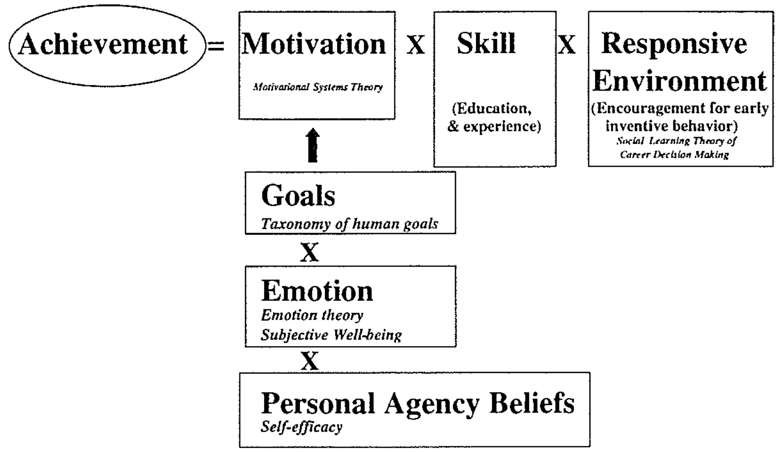

Figure 7.1. Key components influencing achievement. The living systems framework (Ford, 1992).

Linear regression was used to evaluate how skill and motivation (*emotion* and *personal agency*) might be associated with inventor achievement. The regression models for each of the five dimensions of achievement showed strong linear relationships (adjusted r^2 ranged from .19–.47) between achievement and the other components of Ford's motivational systems theory.

Because of the dearth of research scales relevant to inventors in the existing creativity literature, original scales were developed for subjective achievement and for personal agency. Although the scales were strong in theoretical grounding and in content validity by way of inventor review, the absence of existing well-validated scales made it difficult to establish concurrent or convergent validity. The use of original scales can be seen as a limitation of Study 2. It is hoped, however, that these new measures will spawn more research on subjective and objective measures of inventing achievement. Construct validity will come with time as these measures are tested in larger studies.

Internal Motivation

Personal Goals

Goal theory in psychology studies why people do what they do. This is an interesting question in the case of inventors because the process of inventing is often fraught with relentless hours of hard work, criticism, false starts, dead ends, setbacks, and frequent failures (Henderson, 2003). In Study 2, inventors were asked to provide three reasons for why they pursued the inventing work. The vignette responses were then coded according to the Taxonomy of Human Goals (Ford & Nichols, 1991). Figure 7.2 displays a

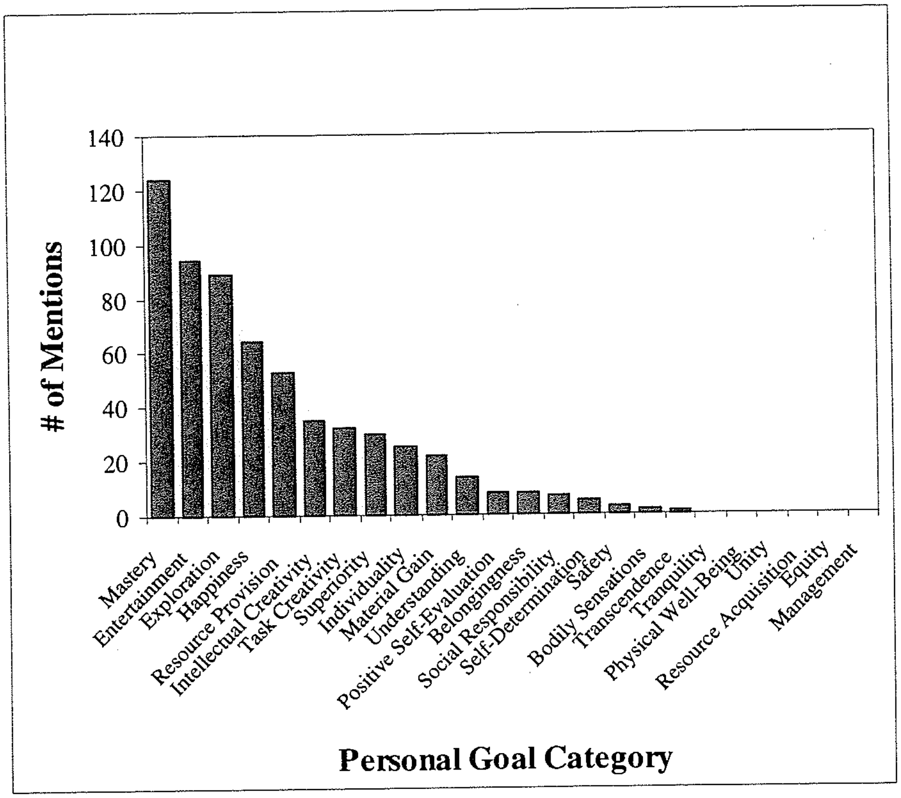

Figure 7.2. Reasons for doing inventing work sorted by frequency of mention. The survey question used was "What are your main reasons for inventing work? Reason 1, Reason 2, Reason 3." 616 reasons were provided by 247 inventors: 229 for Reason 1, 207 for Reason 2, 180 for Reason 3. Reasons were coded using Taxonomy of Personal Goals (Ford & Nichols,1991).

chart of the personal goals reported by the participating inventors sorted by frequency of mention. In descending order of frequency, the most prominent personal goals were mastery, entertainment, exploration, happiness, resource provision, intellectual creativity, task creativity, superiority, individuality, and material gain.

The importance of these findings is threefold. First, seven out of the top ten goals mentioned suggest that inventors are intrinsically motivated in their work. That is, fame, financial remuneration, and competitive advantage were not dominant in their reason for pursuing inventing. Although two extrinsic goals, superiority and material gain, did rank in the top 10 goals for doing inventing work, they were ranked number 8 and 10. Second, mastery was ranked as the number one reason among the inventor participants to explain why they do the work they do. Indeed, the prominence of this personal goal is central to understanding how inventors can withstand the emotional and intellectual stress of inventing work and the constant threat of failure to their ideas. These data suggest that the more significant the challenge, the more fundamental the fulfillment derived from the ultimate accomplishment of invention. Thirdly, the vignettes suggested that entertainment, exploration, enjoyment, and resource provision (i.e., satisfaction and fun) were mentioned as the 2nd to 7th most frequent reasons.

Is intrinsic motivation unique to inventors? No, in fact, it appears that intrinsic motivation is something that inventors share with other types of creative people. Social psychology and other theories of creativity have long noted the importance of intrinsic motivation to creativity (Amabile, 1983; Deci & Ryan, 1985; Hennessey, 1999; Hennessey & Amabile, 1998; Urdan, 1997). When comparing intrinsic goal structures between inventors and artists, it is important to put intrinsic motivation in a context of financial remuneration. Though no salary data were requested in the survey, financial satisfaction data gathered from a subset of the participants (n = 92, 37% of total sample) indicated that they were "fairly satisfied" (5 on a 7-point Likert scale) with their financial compensation. Therefore, it is likely that the salaries of the participants amply covered their minimum financial needs (which may not be the case for all artists early in their career, nor, for that matter, all inventors).

It is also useful to put the intrinsic-motivation data into historical context. There was a flight of talent during the 1990s bull market, when many inventors left their corporate jobs and joined smaller start-up companies for greater financial payoff to their inventing work. This may have had an influence on what goal structures were evident for corporate inventor participants. Study 2 was conducted in February 2001. The inventors who stayed with larger corporations had less upside potential in their earnings than did their colleagues working in start-ups. One might wonder whether those inventors who joined start-up ventures had more extrinsic goal structures than the survey participants, who presumably had kept their more stable albeit less lucrative corporate inventing positions. What is clear and perhaps most significant is that the goal structures of the inventors in the survey did not mirror the media's emphasis on the extrinsic rewards of invention.

Personal Agency or Self-Efficacy

Participants were asked, via a self-efficacy survey, to rate on a 100-point scale (0–100%) how confident they were that they could accomplish 52 specific tasks. The 0% score indicated "not at all confident," and the 100% score indicated "completely confident." The factor analysis performed indicated that the 52 individual questions fell into the three distinct domains of self-efficacy. These were (a) *interpersonal ability*, (b) *hardiness*, and (c) *technical ability*.

On average, participants were 75% confident of their technical ability, 67% confident of their hardiness, and 75% confident of their interpersonal abilities. In the linear regressions, the participants' confidence in technical ability was most strongly associated with all measures. Participant belief in hardiness and interpersonal ability proved to be a significant correlate within the subjective dimensions. The findings are consistent with theories of self-efficacy, learned optimism, and learned resourcefulness, in which proven skill, positive methods of coping, and positive attribution styles for negative events are associated with emotional health and productive lifestyles (Bandura, 1997; Rosenbaum, 1990; Seligman, 1991).

Is a high level of personal agency unique to inventors? According to Bandura (1997) in his review of thousands of self-efficacy studies in a wide range of occupations, strong empirical evidence suggests that self-efficacy is a strong factor in individual and collective achievement. Bandura's well-validated theory clearly suggests, as does Martin Ford's motivational systems theory model (1992), that a high sense of personal agency would be instrumental in any creative endeavor.

Emotion

On average, the participants indicated that they were "very satisfied" at work (6 on a 7-point Likert scale). There were significant differences found in work satisfaction (subjective well-being) across gender but not ethnicity. Female participants were significantly less satisfied at work than their male counterparts, on average. Overall, these results on subjective well-being for inventors suggest that inventing can be a highly rewarding profession. The lower satisfaction among women inventors in a corporate setting may reflect the need for more progress in integrating women in a work environment traditionally dominated by male inventors.

Subjective well-being at work was found to be positively associated with inventing achievement in general, but specifically with only one measure of achievement: sense of accomplishment. The composite measure of subjective well-being was designed as an overall appraisal of happiness at work rather than a process-related measure of the ups and downs associated with inventing over time. More process-related measures of emotional arousal (yet to be developed in the literature) that evaluate the degree of positive emotion experienced at different points in the invention process may well have turned out to be stronger correlates with inventing achievement.

Scholars have long noted the joys of creating among inventors and other creative individuals (Adams, 1972; Bruch, 1988; Csikszentmihalyi, 1996; Henderson, 2003, 2004; Mace, 1997; Rossman, 1964); the role of positive emotion in creative endeavor (Henderson, 2004; Russ, 1993, 1999; Shaw & Runco, 1994); and the centrality of enjoyment, personal fulfillment, and contribution in attaining satisfying work and satisfying lives (Henderson, 1999/2000, 2000b; Krumboltz & Henderson, 2002). Paradoxically the social stereotypes attributed to engineers as depicted in Dilbert cartoons have suggested that the feeling world is out of reach to these technically trained individuals ("Dilbert," Adams, 2003). Conversations with inventors suggest entirely the contrary (Henderson, 2004) when it comes to inventing achievement. In fact, the emotional experience of inventors during the process of inventing was discussed as integral to the process.

Ford (1992) conceptualized emotional arousal as a critical component in mobilizing goal-directed effort. However, the role of emotional arousal in the creative process is highly complex because of the antecedent, concurrent, and consequential emotions that shift from one behavioral episode to another. Spontaneous feelings, such as excitement, frustration, confusion, and exhilaration, have a critical role in stimulating the actions needed to proceed through the arduous creative process (Shaw, 1989). Therefore, it is important to consider the way in which inventors enjoy their work in addition to their overall subjective well-being or the degree of emotional arousal experienced.

Russ (1993, 1999) outlined five affective dimensions found to be significant in the creative process, as derived from her research on children engaging in creative play. These categories were *access to affect laden thoughts*, *openness to affect states*, *affective pleasure in challenge*, *affective pleasure in problem solving*, and *cognitive integration and modulation of affect*. The interview discussions with inventors in Study 1 not only provided evidence to support the Russ model but also encouraged an elaboration and expansion of the model. One category (cognitive integration and modulation of affect) was expanded to include the role of intuition; four other categories were added (*affective pleasure in technical perspective-taking*, *in focus*, *in creating*, and *in self-expression*). These categories suggest that the way in which creativity in general, and the inventing process in particular, is experienced emotionally is highly individualized. How these categories of affect compare with the emotional experience of artists, musicians, and other creative people poses an interesting question for further research.

Skill

Over and above education, the participants in Study 2 had 14 mean years of experience, each with a spread of 9 years normally distributed. *Skill* proved to be significantly associated with all objective dimensions of achievement as well as in one subjective dimension, recognition. In a study of successful, highly creative people, Csikszentmihalyi (1996) asserted that it takes at least 10 years of focused effort, both in terms of education and applied experience, to achieve success in any intellectual domain. This assertion is consistent with the findings in this study.

Environment

Many researchers have investigated early school and home environments of artists and writers (Hébert, 1993; Rostan, 1997; Filippelli & Walberg, 1997) though none of this research has appeared in prominent literature.

Nevertheless, interest in environmental factors that are associated with creative talent is not new. As far back as 1935, Rossman published survey results that indicated that 87.5% of 695 male inventors responded positively to a question on whether they were interested in mechanical things as a boy.

A contemporary view among scholars is that the experiences that we craft for young people in schools and at home have a big influence on whether gifted talent can be actualized into the ability to achieve and contribute (Fetterman, 1990). The importance of classroom environments that support discovery learning for students interested in invention has been influential in engineering design programs (Adams, 1972; Faste, 1972; Henderson, 2000a). Stimulating environments and participatory learning have also been noted for their influence on student engagement and achievement (Astin, 1984; Pace, 1980; Sameroff, 1987).

The impact of the work environment on innovative achievement has also drawn substantial research interest. Several work-environment assessment scales have been developed for use in research and evaluation (see Amabile, 1995; Amabile, Conti, Coon, Lazenby, & Herron, 1996; Moos & Insel, 1974). The most prominent among these scales is the KEYS scale (Amabile, 1995), which evaluates work environment in terms of stimulants and obstacles to innovation.

Because the influence of work environment on creativity in the workplace is well understood, Study 2 focused on formative environments. It is clear that environmental factors shaping an individual's skills, career interests, and orientation toward achievement are complex interactions of person and environment over many behavior episodes. As mentioned above, this places the results of Study 2 on formative environments of inventors squarely within Ford's living systems framework (1992) and also within Krumboltz's social learning theory of career decision making (1979).

In Study 2, the inventor participants were asked in open-ended survey questions for recollections of formative experiences in and outside of school that may have contributed to their ability to invent. The resulting 616 vignettes provided anecdotal evidence for particular features of the environment that may foster inventive behavior. These vignettes were analyzed with the qualitative method of pattern coding (Miles & Huberman, 1994) for evidence of early inventive behavior and for aspects of the environment that supported and encouraged these inclinations.

Figure 7.3 illustrates the central themes evident in the vignettes submitted by the inventor participants. With notable frequency, the inventor participants mentioned having materials and resources that encouraged early inventive behavior. They had access to tools; toys for building things; toys, clocks, appliances and other equipment to take apart; and sometimes garage space, tool benches or tool shops in which to try out their inventive ideas. Both male and female participants had the opportunity to work with parents, extended family, neighbors, advisors, educators, and peers on inventive

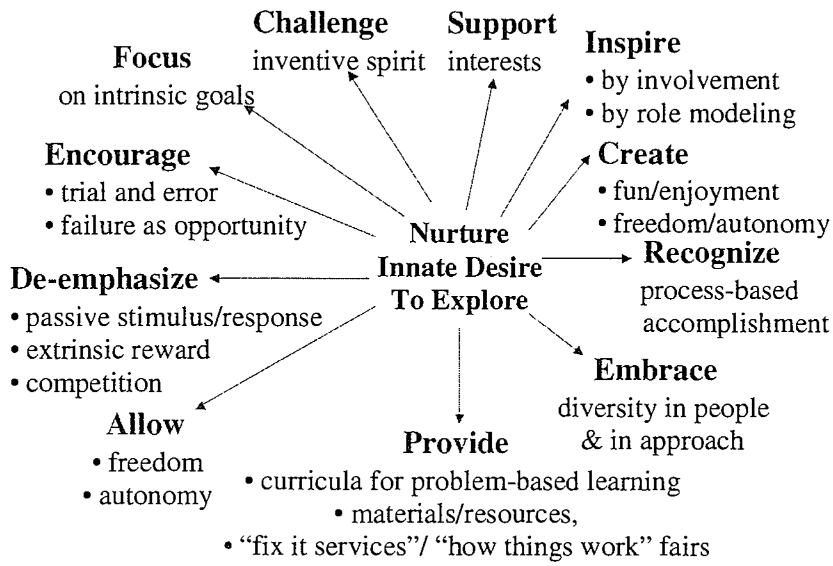

Figure 7.3. Hypothesized features of a formative environment.

projects. The side-by-side collaboration was noted as instructive, inspiring, and enjoyable.

Many of the participants remembered having the opportunity to participate in activities based on active, problem-based discovery learning in early school years up through graduate education. Sometimes, these activities were built into the science and math curricula; other times, the inventors recalled these experiences as being associated with extra-credit projects, team projects for school events (e.g., such as designing the sets for a school play), special projects for the school (e.g., building a darkroom), science fairs, invention grants and competitions, product-design courses as well as graduate theses and dissertations. The participants remembered these forums as those that afforded freedom for their unique ideas to blossom and provided inspiration to express what they knew in terms of tangible discoveries, creations, and inventions.

The participants recalled the freedom they were given to explore their surrounding environments and the tolerance their parents and educators showed if they made a mess, broke something, or shorted out the electrical circuits as a result of their inventive endeavors. Some wrote about how living individuals and famous inventors of the past had inspired them to dream of inventive careers. Through these experiences, many remembered discovering a joy of inventing that endured through to adulthood. Perhaps most important, participants mentioned how, through these discovery forums at home and at school, they learned the value and importance of failure in discovery work and the dominant influence of early childhood successes in their later interest in inventing work.

The Development of Inventing Talent

One key question is whether inventing ability is innate or learned through a series of early life experiences. The express focus of both Study 1 and Study 2, as indicated by choice of underlying theoretical models, was to identify and explore personal attributes of adult inventors and their early environment that were malleable and therefore could be influenced by future initiatives in family, school, and higher education. Therefore, genetic predispositions to inventing were not directly evaluated. The survey questions that asked about influential childhood experiences were designed to elicit information about the inventor participants' early family, community, and school environments. Not surprisingly, the majority of the participants provided evidence for strong environmental influences on their ability to invent later in life. Two participants, despite the wording of the questions, did discuss their belief that their inventing talent was innate.

In the end, anecdotal evidence will not settle a debate as long-standing as that of nature versus nurture, neither in general nor in the study of creativity. Both genetic and environmental influences on creative behavior have been well elucidated in the creativity literature (Simonton, 1999; Sternberg, 1999). In human behavioral biology, Lewontin (1995) and Sapolsky (1998) have emphasized that the general debate of nature versus nurture goes well beyond an either–or debate but instead is a phenomenon of the interaction between genes and the environment.

In terms of limitations of the results on formative environments of inventors, Study 2 relies on participants' memory of their childhood experiences. Henry, Moffitt, Caspi, Langley, and Silva (1994) outlined the accuracy flaws inherent in study designs that rely on retrospective recall. Caution must be exercised when interpreting these results with causal inference. The vignette data from Study 2 on formative environments is best treated as information that can generate hypotheses for experimental and longitudinal studies in how educational, community, and family initiatives might influence future inventing talent.

CONCLUSION

How does one recognize an inventor living next door? One can spot an inventor neither through appearance, fame, role identity, patents, or individual success. One recognizes an inventor through his or her problem-finding vision and strong problem-solving focus. An inventor is likely to have a strong intrinsic motivation toward work, especially motivated by the most difficult of challenges. Good inventors learn to be tenacious, persistent, focused, and open to experience. Some will work exceptionally hard and are likely to deeply enjoy their creative work. Successful inventors are confident in their abilities, backed by a solid resume of educational and hands-on experience. They may even be able to spin an engaging story of childhood working side-by-side with their parents to solve a household need. They may not carry a camera, an easel, or a violin; even without traditional artistic tools, inventors are among the creative masters of the technical world.

APPENDIX 7.1
Inventive Contributions Among Diverse Peoples

The following Web sites recognize the contributions of inventors among

1) Children:
   http://www.inventors.about.com/science/inventors/msubmenuyounginventors.htm
2) African-American people:
   http://www.princeton.edu:80/~mcbrown/display/inventor_list.html
   http://www.si.edu/resource/faq/nmah/afinvent.htm
   http://inventors.about.com/cs/blackinventors/
3) Chinese, Latino, and other people of color:
   http://inventors.about.com/cs/chineseinventors/
   http://inventors.about.com/cs/hispanicinventors/
   http://www.uspto.gov/web/offices/ac/ahrpa/opa/pulse/epulse/pulse0103_4a.htm
4) Women:
   http://inventors.about.com/cs/womeninventors/

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