UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

PREDICTING SCIENTIFIC CREATIVITY: THE ROLE OF ADVERSITY, COLLABORATIONS, AND WORK STRATEGIES

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

JAMIE BARRETT
Norman, Oklahoma
2012

PREDICTING SCIENTIFIC CREATIVITY: THE ROLE OF ADVERSITY, COLLABORATIONS, AND WORK STRATEGIES

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF PSYCHOLOGY

BY

Dr. Michael Mumford, Chair

Dr. Shane Connelly

Dr. Eric Day

Dr. Robert Terry

Dr. Dean Hougen

Acknowledgements

There are many people who contributed to the present effort that I would like to thank. I would like to thank Norman Public Library and Greg Stapp for their contributions to the present effort. I would like to extend thanks to Dr. Michael Mumford, my advisor, for his guidance, and honest feedback on this project in addition to my many endeavors in graduate school. I would also like to thank the members of my committee, Dr. Shane Connelly, Dr. Eric Day, Dr. Robert Terry, and Dr. Dean Hougen for their honest and constructive feedback. William Vessey also deserves thanks for his help throughout the course of this project. Finally, I would like to thank my family for their loving support and encouragement.

Table of Contents

List of Tables

List of Figures

Abstract

There is little doubt that career experiences are held to contribute to scientific achievement, however this relationship has yet to be thoroughly investigated in terms the effects on scientific creativity. In the present study, a historiometric approach was used to examine three areas of adult career experiences common to scientific achievement through the use of biographies. In doing so, prior theoretical work was used to identify career experiences relevant to scientific achievement, and three theoretical models were proposed to account for these experiences – adversity, collaborations, and work strategies. Biographies of eminent scientists were then content coded and analyzed using the components of the three models. The results indicated that the adversity model did not predict scientific creativity, however, the work strategies model and, to some degree, the collaborations model showed some promise in understanding the development of creative potential in scientists. The nature of the significant relationships among the model components and scientific creativity are discussed in addition to their implications for the development of the creative potential of scientists.

Introduction

Creativity, or the generation of ideas that are both novel and useful, and innovation, the implementation of those ideas (Mumford and Gustafson 1988), is often thought only be useful in certain fields, such as the arts and sciences (Mumford, Whetzel, & Reiter-Palmon, 1997). However, creative work can be found in any job that requires tasks that present complex, ill-defined problems where successful performance depends on the generation of novel, useful solutions (Mumford & Gustafson, 1988; Besemer & O-Quin, 1999; Ward, Smith, & Finke, 1999; Ford, 2000). Furthermore, it has become clear that some fields, such as visual arts (Rostan, 1997), engineering (Elkins & Keller, 2003), marketing (Osborn, 1953), and the sciences (Feist & Gorman, 1998), creativity and innovation are not only critical to job performance, but are also necessary for career achievement.

Over time, researchers have sought to understand creativity in the context of career achievement. Some studies have focused on identifying the key cognitive abilities that make creative thought possible (e.g. Merrifield, Guildford, Christensen, & Frick, 1962) in addition to understanding the processes underlying creative thought, such as problem recognition and conceptual combination (e.g., Finke, Ward, & Smith, 1992; Mumford, Supinski, Baughman, Costanza, & Threlfall, 1997). Other studies have sought to identify how dispositional characteristics relate to exceptional achievement (e.g. Barron & Harrington, 1981; Feist, 1999; MacKinnon, 1962), while others have examined the changes in productivity over the course of a person's career (e.g.

Simonton, 1997). Each of these studies provides some additional evidence that there are many factors involved with creative production. One emerging area in which creativity appears to be very important looks at the creative processes involved in long-term career achievement.

Because different Occupations show varying degrees of need for creativity and innovation (Mumford, Whetzel, & Reiter-Palmon, 1997), many scholars have sought to understand these issues by studying high performers in fields where creativity is a critical requirement for career achievement (MacKinnon, 1962). One area in which creativity is particularly beneficial is the sciences (Mumford, Connelly, Scott, Espejo, Sohl, Hunter, & Bedell, 2005; Vandervert, Schimpf, & Liu, 2007), in fact, it has been shown that creativity is key for performance in fields ranging from biology to information technology (Dewitt, 2003). Furthermore, previous qualitative and empirical studies (Feist & Gorman, 1998; Mumford & Gustafson, 1988; Nickerson, 1999; Mumford, Connelly, Scott, Espejo, Sohl, Hunter, & Bedell, 2005) have provided a guide for identifying relevant career experiences within these fields, thus making this a reasonable population to assess. Therefore, the purpose of this study was to investigate how specific types of career experiences influence creative performance in the sciences. More specifically, this study was intended to provide scientific leaders a better understanding of these career experiences so that it may prove useful in their leadership efforts of creative individuals.

Scientific Development

The primary goal of studies examining career experiences and achievement is the understanding of the factors that influence the development of creative potential (Runco, 2003). Initial studies have attempted to understand the development of creative potential in terms of childhood, or early life experiences, essentially asking high achieving scientists about their family background (Berry, 1981; Clark & Rice, 1982; Eiduson, 1962; Rowe, 1951, 1953). Similarly, it has been found that successful scientists tended to come from families that valued autonomy and intellectual pursuits (Mumford & Gustafson, 1988). This is not surprising, considering the findings of Feist and Gorman (1998), in which a comprehensive review was conducted to identify characteristics associated with creative scientists. The researchers found that, when compared to nonscientists and less successful scientists, the creative scientists tended to display a surprising set of personality characteristics, which included not only achievement motivation, but also conscientiousness, autonomy, openness, flexibility, cognitive complexity, self-confidence, dominance, emotional stability, and introversion. These differences in the characteristics of eminent scientists and their less-successful counterparts subsequently bring about the question of how this scientific potential might be developed.

Although many studies have sought to understand the development of creative potential (Feldman, 1999; Nickerson, 1999), it is important to note that development does not stop occurring once an individual has passed childhood. In fact, people will continue to develop throughout their lives, as they both influence and are influenced by their environment (Lerner, Freund, Stefanis, & Habermas, 2001). Along these lines, it has been suggested that dispositional and intellectual characteristics will shape the experiences of individuals over the course of their adult development (Adler, Adam, & Arenberg, 1990; Schooler, Mulatu, & Oates, 1999). Furthermore, throughout a person's career, there is evidence that exposure to multiple problems that are complex and novel in nature can improve creative problem-solving skills (e.g. problem finding, conceptual combination, and idea evaluation; Mumford, Marks, Connelly, Zaccaro, and Reiter-Palmon, 2000). Therefore, from these findings, it is reasonable to suggest that peoples' career experiences will influence not only the development of their creative potential, but more specifically their scientific creativity.

In order to understand how one might go about developing the potential of scientists, the nature of these career experiences must first be considered. Given the aforementioned research regarding the impact of exposure on problem-solving, it could be suggested that there is more to these developmental career experiences and their impact on scientific creativity than simply the acquisition of expertise, which has been shown to be an essential element of creativity (Ericsson & Charness, 1994; Weisberg, 1999). This is not meant to underplay the importance of expertise in creativity, however there seem to be other factors involved with career experiences and scientific development. For example, studies by Knapp (1963) and Knapp and Greenbaum (1952) reported that scientists were likely to have attended undergraduate institutions that provided challenging, yet supportive educational experiences. Similarly, Simonton (1992) and Zuckerman (1977) found that it was not uncommon for successful scientists to have mentors who were also successful scientists. In terms of working conditions, Dunbar (1995) found that the laboratory in which the scientists worked was a key contributing factor to the generation of new scientific ideas for a sample of microbiologists. It follows then that creative development is likely to continue into adulthood, and more specifically, continue with the careers in which the scientists work. Thus, it appears that career experiences may require further investigation into how they can influence scientific creativity.

Career Experiences

Mumford, Connelly, et al. (2005) provide evidence that career experiences, specifically later career experiences, predicted creative productivity better than traditional dispositional variables (e.g. intelligence, critical thinking, etc). In fact, this study also provided evidence that the dispositional variables did not exert their effects on creative performance alone, but instead by operating through career experiences. Also emerging from this line of research was a series of potential career events held to influence creativity in the sciences and engineering. Three particularly interesting areas, adversity, collaborations, and work procedures have been chosen for further examination. Although there has been little other research into understanding adult scientific development, there is still value in investigating these processes so as to better instruct leaders of these individuals. As such, the present effort seeks to understand more thoroughly how adversity, collaborations, and work procedures/strategies can impact creative production in the sciences.

Adversity

It has been argued that individuals with careers in the sciences are frequently faced with adversity, likely involving experiences with failed products, periods of halted progress, lack of financial support, etc. (Subotnik & Steiner, 1994). As such, it then follows that more successful scientists would likely be able to cope with adverse experiences without allowing these them to halt their own professional progress. Moreover, previous research has found that there are distinct career markers involving adversity and how a scientist copes and responds to adversity (Mumford, Connelly, et al; 2005). From these adverse career events, could be suggested that a scientist's capacity to experience adversity and deal with it appropriately may, in fact, impact one's creativity.

In understanding how adverse experiences impact the lives of scientists, one would need to start from the beginning – adverse career events. There are several avenues in which a scientist may experience adversity. Some options put forth contend that scientists may have to fight their way into the field, or some have experienced distrust from a supervisor (Roe, 1966). It is important to note that these events will differ from other forms of adversity, perhaps childhood adversity or difficult personal events one experiences in his/her lifetime. However, the catalyst for understanding how scientists experience adversity is clearly the events themselves.

Upon experiencing these adverse events, it then follows that one would need to engage in coping strategies in order to manage their careers appropriately. As such, this step in the process is essential in allowing the scientist to understand their circumstances and move on from them, thus pointing them in the right direction for overcoming their adverse experiences. Headey and Wearing (1990) identify 5 key coping strategies for dealing with adversity. These strategies include 1) logical analysis, 2) information seeking, 3) problem-solving, 4) affective regulation, and 5) avoidance. Each of these strategies offers a unique benefit to the scientist, so that he/she may employ the appropriate strategy as adverse events are encountered.

Once the coping strategies are engaged, a likely step toward overcoming adversity is the search for opportunities. The opportunity search essentially takes place after one has dealt with the adverse experiences vis-à-vis coping strategies, and is preparing to learn from it. Within this search, which is the next proposed step in overcoming adversity, Tebes, Irish, Vasquez, and Perkins, (2004) have identified two primary objectives. First, the individual must reevaluate the experience from one that was generally negative to one that promotes growth. This critical step allows the individual to downplay any threat or trauma they have experienced and not only move forward, but also learn from their experiences so that they won't encounter a similar negative event again. Second, individuals should recognize that coping with these adverse events has resulted in new opportunities. It is likely that this realization will allow the scientist to approach their ensuing career with a more positive outlook, since he/she has been able to overcome the traumatic event successfully. This viewpoint is likely to impact the scientists' work, such that he/she won't feel held back due to experiencing adversity, thus influencing his/her subsequent creative production in a positive way.

Given this series of steps regarding adversity, one key predictor of creative performance must also occur before the coping strategies are engaged and an opportunity search occurs – motivation. Individuals who are successful in overcoming adversity must be highly motivated, especially when facing failure (Koro-Ljungberg, 2002). Furthermore, intrinsic motivation, as opposed to extrinsic motivation, is consistently, strongly related to creativity and innovation (Amabile, 1985, 1997; Amabile, Hennessey, & Grossman, 1986; Collins & Amabile, 1999), and thus motivation is an important driving factor in this process. Given these steps for overcoming adversity and engaging oneself creatively, Figure 1 presents the proposed theoretical model of adversity and creative performance. Furthermore, regarding this model, the following hypothesis is proposed:

> Hypothesis 1: The adversity model of scientific career experiences will be positively related to creative production in scientists.

Insert figure 1 about here

Collaborations

One particular set of career influences that has received quite a bit of attention over the years attention is collaborations (Abra, 1994; Gardner, 1993). Collaborations are quite common among scientific work, and it has been argued that collaborations are a necessary component of scientific creativity (Sawyer, 2006). Research on this topic has become increasingly certain that creativity is not the result of a solidary individual, but instead is very much a social activity. It has been found that some of the most important creative accomplishments have emerged from collaborative teams and creative circles (Farrell, 2001; John-Steiner, 2000; Sawyer, 2003). Similarly, Zuckerman (1967) examined the publication patterns of Nobel Laureates and found that they were more likely to engage in collaborations than a matched sample of non-laureates. Thus it seems clear that collaborations play a key role in scientific success, however the extent to which these collaborations help to develop scientific creativity has yet to be examined in detail.

In understanding how collaborations may impact scientific creativity, one emerging characteristic of eminent scientists is that they tend to be very professionally active. In fact, most of their relationships are on the professional level (Koro-Ljungbert, 2002), although the nature of these relationships can vary widely. More specifically, scientists are likely to have a large number of professional contacts, some of which may be rivals or associates (Simonton, 1992). Many of these close contact will also be with colleagues in similar but distinct disciplines (Nakamura & Csikszenmihalyi, 2001), allowing for somewhat more diverse interactions. Because of this very active professional activity, it is not surprising that scientists have so many types of professional relationships, which can then lead to potential opportunities for collaboration.

Given that scientists are likely to be presented with many opportunities to collaborate with others (Dunbar, 2000), they must also engage in active collaboration, usually with several others on various projects (Simonton, 1992), to produce something of value. Collaborations among scientists can take many forms and work to benefit them in unique ways. For example, a very useful approach many scientists take is to work with someone whose skills complement his/her weaknesses (Nakamura & Csikszenmihalyi, 2002; Hagen, 1993), while others may choose to collaborate with other prominent scientists (Zuckerman, 1967). These types of interactions provide several opportunities for scientists to actively collaborate with others, thus allowing for a potential increase in scientific creativity.

Collaborations have indeed been shown to be an important part of a scientist’s career , however, without requisite participation activities, these collaborations may not be productive. Along these lines, many eminent scientists tend to have a strong presence while participating in planning sessions with work groups (Hey, Pietruschka, Bungard, Jons, 2000), allowing their ideas and opinions to be more fully considered. Furthermore, for many scientists, their colleagues provide a source of intellectual stimulation (Allison & Long, 1990). This stimulation allows the scientist to more fully engage in collaborative work and thus reap more benefits from it. Interestingly, another common aspect of participation with professional collaborations is that scientists also tend to oscillate between collaborating with others and working alone (Zuckerman, 1967). This idea of switching back and forth between collaboration and individual work can last throughout the scientist's career. These participating actions are likely to influence not only professional relationships, but also opportunities for and the extent to which a person engages in active collaboration, all of which are likely to have an impact on creative production. Thus, Figure 2 illustrates the proposed theoretical model for scientific collaborations. Given that collaborations are clearly important for scientific work (e.g. Sawyer, 2006) and adversity has had mixed findings (e.g. Subotnick & Steiner, 1994; Mumford, Connelly, et al., 2005) the following hypothesis follows:

> Hypothesis 2: The collaborations model of scientific career experiences will be positively related to creative production in scientists.
>
> Hypothesis 3: The collaborations model of scientific career experiences will be a better predictor of scientific creativity than the adversity model.

\-

Insert figure 2 about here

\-

Work Procedures/Strategies

The work strategies that scientists develop over time may have an important role in their career achievement (Zuckerman & Cole, 1994). For example, previous studies have found that the tendency to focus on time-relevant problems, attention to anomalies, and establishing new lines of research is positively related to scientific achievement Mumford, Scott, & Gaddis, 2003; Root-Bernstein, 2003). Mumford, Connelly, et al (2005) also found that career markers of work procedures were strongly related to scientific achievement. Although these findings are consistent, little other work has been done examining the influence of work strategies on scientific achievement. Because of these findings regarding scientific achievement, the issue of work strategies and how they may increase creativity warrants further investigation.

When considering how work procedures can impact scientific creativity, there are several potential factors involved. One likely starting point, to which all other aspects will flow, is a prestige. Specifically, individuals who are very productive tend to have positions with high prestige (Allison & Long, 1990). Along with these prestigious jobs, it is likely that individuals will also maintain gatekeeper positions (Koro-Ljungberg, 2002). These high-achieving positions likely allow scientists to focus on their own work, perhaps structuring their activities with some degree of autonomy. Additionally, this prestige can prove to be a unique starting point for scientists to develop their network, specifically by seeking out industry associations and commercializing their ideas (Louis, Blumenthal, Gluck, & Stoto, 1989). Networks are important for scientific work because broadening one’s scope of connections opens new opportunities for scientists to develop their area knowledge and research options. This can help the individual cultivate a network of similar but distinct research ideas (Gruber & Wallace, 1999) by being exposed to a general mix of projects or areas studied in the individual’s labs (Mumford 2000), which, in turn, allows the individuals to create his/her own original lines of research (Koro-Ljungberg, 2002).

It is then possible that this openness to area knowledge and research can subsequently engage specific strategies involving the way one approaches work. An individual may engage in core research, which is essentially research that is similar to the work already being done. This type of work will tend to be in line with the zeitgeist of the field or organization at the time, which may be more likely to be cited due to popularity (Simonton, 1997). Individuals may also engage in more “fringe” work strategies, or strategies geared toward setting the individual apart from others. These individuals will attend to unexpected findings, perhaps even extending the findings to discover their cause (Dunbar, 2000). Another possible approach would be to engage in strategies more geared toward creative work, such as idea generation and implementation (Mumford, 2002). Each of these approaches provides some framework with which a scientist can approach his/her career, specifically in instances involving creativity. Finally, specific strategies such as using analogies for clarity (Dunbar, 2000) or keeping detailed work notes (Gruber & Wallace, 1999) may also be useful for scientists in their creative efforts. Given that career events involving work strategies are associated with scientific achievement, the theoretical model presented in Figure 3 is proposed. Because work procedures have been shown to predict scientific achievement better than adversity or collaborations, the following hypotheses are submitted:

Hypothesis 4: The work strategies model of scientific career experiences will be positively related to creative production in scientists.

Hypothesis 5: The work strategies model of scientific career experiences will be a better predictor of scientific creativity than the adversity or collaborations models.

Insert figure 3 about here

Method

Historiometric Method

The historiometric method was used in this study to examine how the three models impact creative performance. This method is one in which human behavior is examined using quantitative analysis of historical documents involving prominent individuals. In fact, it is especially useful for studying creative individuals because it allows access to information that would be difficult or impossible to obtain using any other method (Simonton, 1999). Given the population of interest, namely eminent scientists, this method is quite valuable because it not only provides access to this population, but also allows for a large amount of information to be gathered and analyzed for each subject. It is also important, in terms of the present effort, to study creativity in a real-world context (Simonton, 1990). Furthermore, whereas previous studies have either relied on interviews (Hurly, 1996; Zuckerman, 1977) or obituaries

(Mumford et al, 2005), this method also allows for more comprehensive information to be obtained for a particularly difficult population.

Sample

The sample used to examine the influence of the three models on creativity consisted of 93 scientists for whom biographies were written and accessible for the purposes of this study. These scientists were included because they have worked in a number of fields in which creative thought is required. Considering this population consisted of eminent scientists, it is not surprising that, of our sample, 91% were males, and 66% of these scientists had received a PhD in his/her lifetime. Although several specific areas of work in each field were included, 23% of scientists worked primarily in physics and 12% in psychology. For the biographies, the average publication data was 1991, with 82% being published after 1980. The average page length for each book was 340 pages.

Biography Sampling

When selecting scientists and biographies to be included in this study, the procedures recommended by Simonton (1999) for historiometric studies of eminent individuals were followed carefully. Before biographies were selected, a number of criteria had to first be met. First, a list of potential scientists across several fields was generated using a general internet search. From this list, individuals who died before 1920 were removed. With the remaining scientists, a biography search was conducted using the WorldCat book database. Results of this search were filtered by dropping books published prior to 1950, autobiographies, and books written for a juvenile audience. The remaining biographies were then selected for further review. If there were more than 3 viable biographies for a particular scientist, the most recent 3 books were selected. Next, a search was conducted for reviews on each remaining book. Books with positive reviews were included in the final list, books with negative reviews were removed, and books without reviews were included in a separate list of books to be reviewed individually by the two graduate students studying Industrial/Organizational Psychology.

The judges then read each book, paying special attention to the level of documentation, factual information vs. opinion, and level of detail in the description of events. Furthermore, passages were selected that contained information involving a scientists’ experiences with adversity, their work collaborations, and the work procedures and work strategies in which the scientist engaged. After the initial selection of passage containing relevant information took place, the judges conducted another round of passage selection in which the passages were cut down again so as to contain as little extraneous information as possible. By cutting down the information two times, the optimal amount of relevant information was able to be identified for additional judges to rate. The two judges also had periodic checks to ensure that they were both selecting the appropriate passages; the interrater agreement for these selected passages was .78, and the average length of passages selected from each biography was 35 pages. Figure 4 presents a list of each scientist and biography included in this study.

Insert figure 4 about here

Controls

To ensure that conclusions drawn regarding the influence of adversity, collaborations, and work procedures on scientific creativity were not influenced by extraneous variables, two sets of control measures were obtained. These control measures were based on judges' evaluations of the selected passages from the biographies and on the scientist his/herself.

For the first set of control measures, information pertaining to the biography was obtained. Specifically, these controls contained a) the date of publication, b) the page length of the book, c) the extent to which the author focused on facts, d) the extent to which the author focused on opinions, e) original language of the book, f) strength of documentation, specifically the extent to which the author provided support for the information they present, and g) the level of detail author used on developmental events.

The second set of control measures was intended to take into account characteristics of the scientists. These controls included a) sex, b) field, c) education level, d) amount of time working on projects, e) amount of time spent in lab, f) primary country of work, g) scientist's nationality, h) extent to which scientist worked in a lab, i) extent to which scientist worked in the field (applied work), j) amount of support for projects (from organization, peers, etc), k) focus on work (e.g. was work the center of his/her life), l) awards, m) number of external (i.e. non-work) commitments, and n) number of professional commitments. Figure 5 provides examples of these control ratings.

Insert figure 5 about here

The ratings were each set of controls were completed by 6 judges (all industrial and organizational psychology doctoral students) with an interest in creativity. Because this group had 6 total judges, the raters were split into 2 groups of 3 raters, so that each group would rate ½ of the total biographies. To ensure that the judges had an adequate basis for making these inferences, they were all exposed to a 40 hour training program over the course of 6 weeks. At the outset of this training program, judges were given a packet which included the scales for each set of controls. They were also given a sample of biographies to use for familiarizing themselves with the scales, to practice using the scales, and to determine the types of information that is indicative of each metric. This also allowed the raters to identify any scales that were unclear or needed to be re-worked. Next, a series of meeting took place, in which all raters discussed the scales and the practice ratings. In these meetings, judges compared ratings, discussed their reasoning, and identified inconsistencies. Judges then came to consensus on what the appropriate ratings should be for each practice biography. The judges then did two more practice rounds of ratings and follow-up meetings until consistency was reached. The ratings for these biographies were not included in the final analyses. It is of note that these raters were also trained to rate the criteria measures during this time. The average internal agreement coefficient for the control measures was .85 based on Shrout and Fleiss's (1979) method of assessing interrater agreement.

Predictors

Material to be used in the content analysis of the biographies was developed after reviewing prior studies (e.g. Mumford, Connelly, et al., 2005; Feldman, 1999; Feist & Gorman, 1998; Simonton, 1984; Taylor & Barron, 1963) that examined creative development of scientists in terms of their career experiences with adversity, collaborations, and work procedures and strategies. Within these categories, the literature was reviewed to determine which specific aspects of each model could be measured given the sample and nature of the variable. Based on the proposed models for predicting scientific creativity, specific indicators associated with each component of the model were identified. For example, in the adversity model, the adverse events category included variables related to a) supervisory distrust, b) having to fight into the field, and c) overcoming adversity early in career. From this search, on average, each component of the three models was composed of approximately 3 indicators.

After identifying and operationally defining the indicators for each component of the models, behavioral markers were developed to identify the presence of each indicator in the biographies. These benchmark ratings scales were developed using a variation on the procedures recommended by Redmond, Mumford, and Teach (1993). Specifically, two psychologists were asked to read a sample of 10 biographies of eminent scientists. From these biographies, the two scientists identified three statements exhibiting objective behaviors associated with high, medium, and low performance on each of the indicators. Figure 6 provides examples of these benchmark rating scales.

Insert figure 6 about here

Nine judges were asked to evaluate the biographies using these rating scales. Again, judges were all doctoral students in industrial and organizational psychology with an interest in creativity research. Similar to the control and criteria rating group, this group also had enough judges to split them into groups. In this case, there were 3 groups of 3 raters, allowing each group to rate approximately 1/3 of the biographies, which helped guard against rater fatigue. Again, similar to the control and criteria group, each judge underwent a training program to ensure that they had an adequate basis for making the requested inferences. This training program took approximately 50 hours over the course of 6 weeks, and followed the same procedures that were mentioned previously. In short, judges were given time to review the scales and practice using them on a sample of biographies. Then a series of consensus meetings took place, in which the scales were reworked if necessary, information not available in the biographies was identified, and discussion regarding appropriate ratings took place. These meetings continued until adequate reliability for each of the components of the models was reached, which is presented in Table 1. Additionally, based on positive correlations among the observed criteria, judges average ratings on each scale were aggregated to provide an overall assessment of each component of the models.

Evidence bearing on the validity of these scales can be found in the correlations among the model components. Specifically, for adversity motivation was found to positively correlate with both coping strategies (r = .23) and opportunity search (r =.30). The collaborations model showed that professional activity was positively related to opportunities for collaboration (r = .21). For work procedures, fringe search was positively related to general strategies (r = .21), which makes sense considering both are possible approaches to strategy application. Furthermore, area knowledge and research was positively correlated with both general strategies (r = .39) and specific strategies (r = .21), which corresponds with the proposed model.

Criteria

In order to examine how the three models (adversity, collaborations, and work procedures and strategies) were related to creative performance, three types of performance measures were developed. The first set of measures examined the different types of influence that the scientist had on others, and was obtained from information available in the biographies. Specifically, these measures examined the scientist's influence on a) individuals, b) groups, c) organizations, d) the field in which he/she worked, e) theoretical work within the field, and f) technical work within the field.

Ratings on these dimensions of scientific creativity were developed using benchmark rating scales. The behavioral rating scales were developed with an approach similar to the predictors, using a variation of the procedures recommended by Redmond, et al (1993), in which two psychologists reviewed a sample of 10 biographies. Again, based on the material available in the biographies, these psychologists determined three statements for each metric, one statement for each high, medium, and low occurrence. Figure 7 provides examples of these rating scales.

Insert figure 7 about here

The second set of creative performance measures was intended to measures objective indicators of scientific productivity. With the information available in the biographies, counts were obtained for, a) the number of creative products attributed to the scientist, b) the number of organizations that the scientist led, c) the number of groups that the scientist led, and d) the number of individuals that the scientist led. Because raters were only given selected passages from the biographies, there were some instances in which the information was not available. In these cases, a general internet search was then conducted to supplement these counts.

The first and second set of performance measures were obtained by the same 6 raters that were used for rating the controls. The training procedures mentioned previously were employed simultaneously to train the raters on the criteria measures while they were also being trained to rate the controls. The average interrater agreement coefficient for the control measures was .71. The final performance indicator used in this study was Jorge E. Hirsch's h-index. This measure provides a fairly simple and unbiased way of computing the impact of a scientist's research contributions. As such, this index measures both the productivity and impact of the published work of a scientist. It is determined by the scientist's most recent papers in addition to the number of citations the scientist has in other publications. The h-index for each scientist was obtained through the citations-gadget available in Google Scholar.

In order to simplify these performance ratings into the underlying factors, a factor analysis was conducted using a principal components analysis with a varimax rotation. It was determined by a examining a scree plot that five factors should be maintained. The first factor extracted, accounting for 19% of the variance, was labeled *social influence*. This factor was determined by using the loadings produced by the measures involving a scientist's influence on individuals (r = .88), groups (r =.69), organizations (r =.64) and the number of organizations led (r =.78). The second factor extracted accounted for 15% of the variance and was called *theoretical influence*, which was determined by the loadings of the scientist's influence on theoretical work in the field (r =.91) and the number of individuals led (r =.52). The third factor extracted, which accounted for 13% of the variance was called *technical influence* and was determined by the loadings produced by the scientist's influence on technical work in the field (r =.85), influence the field in general (r =.63), and number of creative products (r =.49). The forth factor extracted accounted for 13% of the variance and was labeled *groups led* determined by the loadings of the single variable, number of groups led (*r* =.93). The fifth factor extracted accounted for 13% of the variance and was labeled *professional influence* because of the single variable loading, the h-index (*r* =.87).

Analyses

To assess the relationship of the models of adversity, collaborations, and work procedures with scientific creative performance, the components of each model were correlated with the performance factors. Next, in separate analyses, the characteristics of each of the 3 models were used as predictors of each of the performance factors. In these analyses, control measures were entered in the first block, followed by the predictors for each model, so that gains in prediction can be assessed. Control measures were retained at the .05 significance level.

Results

Correlations

The correlations among the model characteristics and performance factors are shown in Table 1. The overall pattern of relationships within the correlations provides some evidence for the construct validity (Messick, 1989) of the ratings. For example, for the adversity model variables, motivation was positively correlated with theoretical influence (*r* = .24). The collaborations model also provided evidence of validity, specifically the performance factor social influence was positively correlated with both professional relationships (*r* =.30) and participation (*r* =.30). The work procedures model provides perhaps the most compelling validation evidence. Specifically, theoretical influence was shown to be positively correlated with prestige (*r* =.25), area knowledge and research (*r* =.34), and general strategies (*r* =.26), but it was negatively correlated with core research (r = -.26). Additionally, technical influence was positively correlated with network (r =.30), general strategies (r =.26), and more strongly with fringe research (r =.41). These relationships of each model with the outcomes would indeed be expected if the models themselves were correct in terms of the direction of the relationships.

Insert table 1 about here

Regressions

Table 2 presents the correlations between the control variables and scientific creativity. Table 3 presents the findings for each of the factors and models. In the first analysis, the social influence factor when was regressed on each of the three models. A significant multiple correlation was found for the control variables (R = .57, $p \leq .001$), with support from organization, peers, etc (β =.45) and focus on work (β =.45) exhibiting positive relationships with social influence. There were no gains in prediction observed for any of the three models.

Next, the theoretical factor was regressed on each of the three models. A significant multiple correlation was again found for the control measures (R = .54, $p \leq .001$). Work in lab (β =.71) provided the strongest control measure for theoretical influence while work in field (β =.39) and strength of documentation (β =.26) were also significant. A significant multiple correlation was found when the collaborations model variables were added (R = .66, $p \leq .01$). Significant predictors of theoretical influence in the collaborations model were found with opportunities for collaboration (β =.20) and participation (β = .27). The work procedures/strategies model also provided significant gains in prediction (R =.64, $p \leq .05$). It was found that a both network (β = -.21) and core research (β = -.18) were significantly, negatively related to his/her theoretical influence, while knowledge and research evidenced a positive relationship (β =. 20).

Insert table 2 about here

In the next analysis, technical influence was regressed on the three models. The control measures again resulted in a significant multiple correlation (R = .53, $p \leq .01$). Education level (β =.26) and support form organization, peers, etc. (β =.34) were found to positively predict technical influence, while strength of documentation (β = -.25) maintained a negative relationship. The characteristics of the work procedures/strategies model also resulted in a significant multiple correlation (R = .68, $p \leq .001$). In this case, fringe search was found to be the strongest predictor of technical influence (β =.32). Interestingly, Negative relationships were also found with specific strategies (β =-.22) and prestige (β = -.17).

Finally, the groups led and professional influence factors were regressed on the three models. One control measure resulted in a significant multiple correlation (R = .25, $p \leq .03$), with education level exhibiting a negative relationship with groups led (β =-.25). No controls were significant for professional influence and none of the models added to prediction for groups led or professional influence.

Discussion

Before turning to the broader implications of this study, a few limitations should be noted. The sampling procedures used in this study were intended to allow for a diverse sample of scientists whose career activities could be adequately identified and assessed. The use of biographies allowed the judges to assess these career activities, however, only a small number of high quality biographies could be obtained and assessed, thus, our sample size was somewhat thinner than expected. Although, due to the large amount of information obtained from the high quality biographies examined in this study, the sample size is not so concerning. Further, this study focused on the careers of eminent scientists, who are few and far between, the number of appropriate biographies that could potentially be used is quite small, leaving the researchers with an already limited population.

Also, considering the use of biographies to identify relevant behaviors, one other limitation should be mentioned. While biographies can provide a large amount of information on scientists' activities, these events are limited to the details that the author has deemed important and provided. However, because the biographies allowed for a large amount of information regarding the predictors and criterion of interest to be obtained for each scientist, the biographies appeared to be an adequate source of information for the study.

Additionally, this study used biographies to obtain information bearing on both the proposed models and scientific performance. This methodological issue could cause the relationships obtained between the models and performance to be inflated. Although several control variables were put in place to minimize this bias, the issue is still of some concern.

Finally, it should be mentioned that the purpose of the present effort was to examine the influences of eminent scientists. As such, individuals included in this study tended to be fairly high performing scientists who had biographies written about their life and work. Therefore, the findings would not be applicable in a different population, specifically that of scientists who do not perform on the same level as those included in this study.

Given these limitations, the present study does have some noteworthy implications for understanding the development of scientific performance, in terms of scientific creativity. Previously, it has been argued that creativity is not required for scientific achievement (Hurley, 1996). The results in this study, specifically those involving creative work strategies and, to some extent, collaborations, show that scientific achievement does, in fact, involve creativity (Gruber & Wallace, 1999). Furthermore, the findings from this study provide some evidence that the more traditional ways of looking at the impact of experiences on creativity may need to be reevaluated, as was apparent with the lack of findings for the model of adversity.

Again, although there were no findings for adversity, the extent to which a scientist engages in specific collaborative activities and work strategies was found to predict his/her scientific creativity, specifically the scientist's theoretical influence. This finding is interesting because it is conflicts with the perspective that some may have, that individuals who are better able to cope with adverse experiences will be more creative. However, this clearly was not the case. With the collaborations model, reasonably strong relationships were observed with participation activities and opportunities for collaboration. This finding underscores the importance of participation in scientific collaborations, specifically by being an active contributor in scientific endeavors. It is simply not enough for scientists to be active in their professional lives or to have several professional contacts with which to work, instead more active engagement is needed. Furthermore, it is not only the case that scientists engage in participation activities, but also having multiple opportunities in which to collaborate with others also helps increase the scope of their theoretical influence.

Several facets of the work strategies model also showed fairly strong relationships with theoretical performance. Interestingly, a scientist's networking activities, specifically commercializing his/her ideas, was shown to negatively relate to theoretical influence. Perhaps because creative individuals tend to have dispositions related to intellectual achievement (Mumford, Connelly, et al., 2005), such as intelligence, critical thinking, achievement motives, etc (Barron & Harrington, 1981; Feist, 1999; Mumford & Gustafson, 1988), that they tend to find this active networking to be too self-promoting and distracting from the actual work being done. Furthermore, core research, or research similar to others in the field, was negatively related to theoretical influence. Given that creative work generally involves processes underlying the generation and implementation of ideas (Vincent, Decker, & Mumford, 2002), it is likely that individuals who try to “sell” others on their ideas or who conduct unoriginal research will be of less value with regard to creative efforts.

Furthermore, for the work strategies model, area knowledge and research was found to fairly strongly predict theoretical influence. It is not surprising that this portion of the model was associated with creativity, given that expertise, a critical component of the area knowledge portion of the model, has been shown to be critical for creativity in the sciences (Ericsson & Charness, 1994; Weisberg, 1999). Additionally, area knowledge and research involves a mix of projects and lines of work, which allows the individual to explore new potential avenues for research. In fact, Root-Bernstein, Bernstein, and Garnier (1995) found, for eminent scientists, periodic shifts in their focus of research was necessary for long-term productivity. Because creative work tends to be very intense in terms of cognitive resources, the shifts in work and mixing of projects will perhaps allow scientists to manage their cognitive resources more efficiently, thus allowing them more opportunity to engage in creative thought.

The work strategies model was also found to predict technical influence, although the pattern of results differs substantially. Along these lines, fringe search, or the extent to which individuals attend to unexpected findings, happens upon findings, and combine and reorganize data in original ways, was the strongest predictor of technical influence. This is not surprising, considering that these fringe search activities are more along the lines of previous work involving creativity, specifically problem-finding (Getzels & Csiksentmihalyi, 1976; Okuda, Runco, & Berger, 1991; Reiter-Palmon, Mumford, & Threlfall, 1998) and conceptual combination (Finke, Ward, & Smith, 1992; Mobley, Doares, &

Mumford, 1992). Moreover, these components of fringe search tend to involve more original thought processes, and creative work tends to involve tasks that are both complex and ill-defined, where success depends the generation of novel, useful solutions (Besemer & O'Quin, 1999; Ford, 2000; Mumford & Gustafson, 1988; Ward, Smith, & Finke, 1999), therefore, these thought processes may represent a necessary component of scientific creativity.

Although these positive predictors of scientific creativity appear promising, some negative relationships also emerged. Specifically, prestige was found to hurt technical influence, as did specific strategies, or strategies involving analogies, detailed notes, and qualitative reasoning. These findings are interesting in that many scientists tend to have prestigious positions (Allison & Long, 1990). However, in terms of their influence on the technical world, prestige appears to be a detrimental. It is possible that this relationship was found because prestige is something that takes time to acquire, whereas creative work can take place throughout a person's lifetime. It could also be the case that, once an individual obtains a prestigious position, or multiple positions, their responsibilities change in that they become distracted from creative work. Furthermore, use of specific strategies was found to negatively predict technical influence. This is also odd, because these strategies tend to be used by scientists who are fairly productive (Holyoak & Thahard, 1997 Dunbar, 2000; Gruber & Wallace, 1999). When it comes to scientific creativity, it seems that fringe research strategies are more important than application of specific strategies.

The findings from these models with regard to scientific creativity bring about several interesting points regarding the understanding of adult scientific development. First, not a single portion of the adversity model was found to predict scientific creativity. This model was tested because previous research on the effects of adversity on creativity is inconsistent. Specifically, Subotnick and Steiner (1994) found adversity to be associated with high-achieving scientists, whereas Mumford, Connelly, et al. (2005) reported that low-achieving scientists tended to experience adversity. As such, it was suggested that adversity may actually inhibit the individual from exposure to experiences that promote scientific development. Given that the majority of evidence (Mumford & Gustafson, 1988) supports the notion that high-achieving scientists come from supportive backgrounds, this absence of significant findings for adversity is not surprising. Furthermore, the purpose of the present effort was to understand scientific creativity, other areas of research (e.g. visual arts; Rostan, 1997) may result in different findings for adversity.

Although the adversity model did not appear to predict scientific creativity, the collaborations model did show some degree of support, specifically involving participation in opportunities for collaboration. Given that most problems encountered by scientists are quite complex, multiple forms of expertise may be necessary to solve the problem at hand, thus collaborations are likely required (Abra, 1994; Dunbar, 1995; Cagliano, Chiesa, & Manzini, 2000). Although it has been proposed that collaborations are necessary for creativity (Sawyer, 2006), our findings regarding scientific creativity are quite limited.

Keeping this in mind, the present effort was focused primarily on eminent scientists, who are highly successful and productive. Therefore, it may be the case that, for this particular population, collaborations don’t necessarily enhance creativity. This is not to say that they aren’t engaging in collaborations, but perhaps, at a certain point in one’s career, collaborations become a functional work demand rather than a method of increasing creativity. Scientists do tend to collaborate with others quite frequently, however these interactions may simply be part of the work, thus not providing any benefit above and beyond the completing the task at hand.

Of the three models examined, the work strategies model was found to be the best predictor of scientific creativity. This is an interesting finding, in that previous interview studies of scientific achievement haven’t necessarily shown the importance of a scientist’s methods and strategies for approaching his/her work (Hurley, 1996; Zuckerman, 1977). It may be the case that interview studies have over-emphasized certain aspects of a person’s life, and underemphasized others. Specifically, scientists may not be as willing to talk about their work strategies, but more likely to talk about their experiences with adversity or collaborations. Such biases in information collected from these methods may help explain why this approach to understanding scientific development hasn’t received more attention.

Furthermore, the findings regarding work strategies provide much insight into developing scientific creativity. Although early experiences can prove valuable, when it comes to adult scientific achievement, interventions could be put in place to help foster creativity at work. As such, the findings indicate that there may be some benefit from training programs on certain work procedures and laboratory management techniques (Dunbar, 1995; Lerner & Tubman, 1989; Root-Bernstein, 2003). Specifically, an intense, demanding educational program based upon developing creative work strategies (Mumford & Gustafson, 1988) could be a useful tool for leaders of scientific efforts. Along these lines, it seems that a life span approach may be useful in attempting to understand how these talents develop over time, as individuals encounter new experiences throughout their careers (Gruber & Wallace, 1999). By bringing interventions intended to develop creativity out of the childhood classroom and into the adult working world, it is likely that individuals can better understand not only how to foster their own creativity, but also leaders of these efforts can have insight into developing others.

Of course, a major take-home point of this study is that there is a clear need for application of strong interactional models in attempts to understand the development of scientific potential (Nickerson, 1999). Although the findings of the present study suggest that a shift should be made from adversity, and, somewhat, from collaborations, to the individual’s approach to his/her work, more research is needed in understanding how scientific creativity develops over time. The three models examined here provide some preliminary understanding of these processes, however there are likely other explanations, and other models, to account for the observed differences. With that in mind, these findings also elicit the need for studies examining other variables involved in scientific development, for example work context, in understanding scientific potential (Ekvall & Ryhammer, 1999; Oldham & Cummings,1996). The goal of this study was to provide some insight into the development of scientific creativity, and, hopefully, the findings from this investigation will provide a basis for future research along these lines.

References

Abra, J. (1994). Collaboration in creative work: An initiative for investigation. *Creativity Research Journal, 7*, 1–20.

Adler, A. G., Adam, J., & Arenberg, D. (1990). Individual differences assessment of the relationship between change in and initial level of adult cognitive functioning. *Psychology and Aging, 5,* 560–568.

Allison, P. D., & Long, J. S. (1990). Departmental effects of scientific productivity. *American Sociological Review, 55,* 469–478.

Amabile, T. M. (1985). Motivation and creativity: Effects of motivational orientation on creative writers. *Journal of Personality and Social Psychology, 48,* 393-399.

Amabile, T. M. (1997). Entrepreneurial creativity through motivational synergy. *Journal of Creative Behavior, 31,* 18-26.

Amabile, T. M., Hennessey, B. A., & Grossman, B. S. (1986). Social influences on creativity: The effects of contracted-for-reward. *Journal of Personality and Social Psychology, 50,* 14-23.

Barron, F., & Harrington, D. M. (1981). Creativity, intelligence, and personality. *Annual Review of Psychology, 32,* 439-476.

Berry, C. (1981). The Nobel scientists and the origins of scientific achievement. *British Journal of Sociology, 32*, 381–391.

Besemer, S. P., & O'Quin, K. (1999). Confirming the three-factor creative product analysis matrix model in an American sample. *Creativity Research Journal, 12,* 287-296.

Cagliano, R., Chiesa, V., Manzini, R. (2000). Differences and similarities in managing technological collaborations in research, development, and manufacturing: A case study. *Journal of Engineering Technology Management, 17*, 193-224.

Clark, R. A., & Rice, G. A. (1982). Family constellations and eminence: The birth orders of Nobel Prize winners. *The Journal of Psychology*, *110*, 281–287.

Collins, M. A., & Amabile, T. M. (1999). Motivation and creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 297-312). Cambridge, England: Cambridge Univ. Press.

Dewitt, T. (2003). Understanding the relationship between Information Technology and creativity in organisations. *Creativity Research Journal*, *15*, 167-182.

Dunbar, K. (2000). How scientists think in the real world: Implications for science education. *Journal of Applied Developmental Psychology, 21*, 49–58.

Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In R. J. Sternberg & J. E. Davidson (Eds.), *The nature of insight* (pp. 365–395). Cambridge, MA: MIT.

Eiduson, B. T. (1962). Scientists: Their psychological world. New York: Basic Books.

Ekvall, G., & Ryhammar, L. (1999). The creative climate: Its determinants and effects at a Swedish university. *Creativity Research Journal, 12*, 303–310.

Elkins, T., & Keller, R. T. (2003). Leadership in research and development organizations: A literature review and conceptual framework. *The Leadership Quarterly, 14*, 587–606.

Ericsson, K., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist, 49*, 725-747.

Farrell, M.P. (2001). *Collaborative circles: Friendship dynamics and creative work.* Chicago: University of Chicago Press.

Feist, G. J. (1999). The influence of personality on artistic and scientific creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 273–269). Cambridge, England: Cambridge University Press.

Feist, G. J., & Gorman, M. E., (1998). The psychology of science: Review and integration of a nascent discipline. *Review of General Psychology, 2,* 3-47.

Feldman, D. H. (1999). The Development of Creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 169-188). Cambridge, England: Cambridge University Press.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. Cambridge, Massachusetts: MIT Press.

Ford, C.M. (2000) Creative Developments in Creativity Theory. *Academy of Management Review*, 25, 284–9.

Gardner, H. (1993). *Creative minds: An anatomy of creativity as seen through the lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, Ghandi*. New York: Basic.

Getzels, J., & Csikszentmihalhyi, M. (1976). *The creative vision: A longitudinal study of problem-finding in art.* New York: Wiley-Interscience.

Gruber, H. E., & Wallace, D. B. (1999). The case study method and evolving systems approach for understanding unique creative people at work. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 93–115). Cambridge, England: Cambridge University Press.

Hagen, J. B. (1993). Clementsian ecologists: The internal dynamics of a research school. *Osiris, 8*, 178–195.

Headey, B., Wearing, A. (1990). Subjective well-being and coping with adversity. *Social Indicators Research, 22*, 327-349.

Hey, A. H., Pietruschka, S., Bungard, W., & Jons, I. (2000). Feedback as a supporting system for work groups. In M. Vartiainen & F. Avallone (Eds.), *Innovative theories, tools, and practices in work and organizational psychology*. Seattle,WA: Hogrefe.

Holyoak, K. J., & Thagard, P. (1997). The analogical mind. *American Psychologist, 52,* 35-44.

Hurley, J. (1996). *Organization and scientific discovery*. Chichester, England: Wiley.

John-Steiner, V. (2000). *Creative collaboration.* New York: Oxford.

Knapp, R. H. (1963). Demographic, cultural, and personality attributes of scientists. In C.W. Taylor & R. Barron (Eds.), *Scientific creativity: Its recognition and development* (pp. 205–216), New York: Wiley.

Knapp, R. H., & Greenbaum, J. C. (1952). *The younger American scholar: His collegiate origins*. Chicago: University of Chicago Press.

Koro-Ljungberg, M. (2002). Constructions of high academic achievement through the analysis of critical events. *Gifted Child Quarterly, 46*, 209–233.

Lerner, R. M., & Tubman, J. G. (1989). Conceptual issues in studying continuity and discontinuity in personality development across life. *Journal of Personality, 57,* 343–373.

Lerner, R. M., Freund, D. E., Stefanis, I. D., & Habermas, T. (2001). Understanding developmental regulation in adolescence: The use of the selection, optimization, and compensation model. *Human Development, 44*, 29–50.

Louis, K.S., Blumenthal, D., Gluck, M.E., Stoto, M.A. (1989). Entrepreneurs in academe: An exploration of behaviors among life scientists. *Administrative Science Quarterly, 34,* 110-131.

Mackinnon, D. (1962). The nature and nurture of creative talent. *American Psychologist, 17*, 484–495.

Merrifield, P. R., Guilford, J. P., Christensen, P. R., & Frick, J. W. (1962). The role of intellectual factors in problem solving. *Psychological Monographs, 76,* 1-21.

Messick, S. (1989). Validity. In R L. Linn (Ed.), *Educational measurement* (pp. 13–103). Princeton, NJ: MacMillan.

Mobley, M.I., Doares, L.M., & Mumford, M.D. (1992). Process analytic models of creative capacities: Evidence for the combination and reorganization process. *Creativity Research Journal, 5(2),* 125-155.

Mumford, M. D. (2000). Managing creative people: Strategies and tactics for innovation. *Human Resource Management Review, 10,* 313-351.

Mumford, M. D., & Gustafson, S. B. (1988). Creativity syndrome: Integration, application, and innovation. *Psychological Bulletin, 103,* 27-43.

Mumford, M. D., Marks, M. A., Connelly, M. S., Zaccaro, S. J., & Reiter-Palmon, R. (2000). Development of leadership skills: Experience and timing. *Leadership Quarterly, 11*, 87-114.

Mumford, M. D., Scott, G. M., & Gaddis, B. (2003). Leadership in scientific organizations. In R. J. Hurley (Ed.), *Scientific research effectiveness: The organizational dimension* (pp. 69–100). Dordrecht, Netherlands: Kluwer.

Mumford, M. D., Scott, G., Gaddis, B., & Strange, J. (2002). Leading creative people: Orchestrating expertise and relationships. *Leadership Quarterly, 13*, 705-750.

Mumford, M.D., Connelly, S.M., Scott, G., Espejo, J., Sohl, L.M., Hunter, S.T., Bedell, K.E. (2005). Career experiences and scientific performance: A study of social, physical, life, and health sciences. *Creativity Research Journal, 17*, 105-129.

Mumford, M.D., Supinski, E.P., Baughman, W.A., Costanza, D.P., & Threlfall, K.V. (1997). Process-based measures of creative problem-solving skills: I. Overall prediction. *Creativity Research Journal, 10,* 77-85.

Mumford, M.D., Whetzel, D.L., & Reiter-Palmon, R. (1997). Thinking creatively at work: Organization influences on creative problem solving. *Journal of Creative Behavior, 31(1),* 7-17.

Nakamura, J., & Csikszentmihalyi, M. (2002). Catalytic creativity: The case of Linus Pauling. *American Psychologist, 56,*337–341.

Nickerson, R. S. (1999). Enhancing creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 392–430). Cambridge, England: Cambridge University Press.

Okunda, S.M., Runco, M.A., & Berger, D.E. (1991). Creativity and the finding and solving of real-world problems. *Journal of Psychoeducational Assessment, 9*, 145-153.

Oldham, G. R., & Cummings, A. (1996). Employee creativity: Personal and contextual factions at work. *Academy of Management Journal, 39,* 607–634.

Osborn, A. F. (1953). *Applied Imagination*. New York; Scribner's.

Reiter-Palmon, R., Mumford, M. D., & Threlfall, K. (1998). Solving everyday problems creatively: The role of problem construction and personality type. *Creativity Research Journal, 11*, 187-197.

Roe, A. (1951).A psychological study of physical scientists. *Genetic Psychology Monographs*, *43*, 121–235.

Roe, A. (1953). *The making of a scientist*. New York: Dodd Mead.

Roe, A. (1966). Women in Science. *The Personnel and Guidance Journal, 44*, 784-787.

Root-Bernstein, R. S. (2003). The role of enculturation in scientific innovation: A case study of combinational chemistry at Parke-Davis. In J. Hurley (Ed.), *Scientific research effectiveness: The organizational dimension* (pp. 165–196). Dordrecht, Netherlands: Kluwer.

Root-Bernstein, R. S., Bernstein, M., & Garnier, H. (1995). Correlations between avocations, scientific style, work habits, and professional impact of scientists. *Creativity Research Journal, 8,* 115–137.

Rostan, S. M. (1997). A study of young artists: The development of artistic talent and creativity. *Creativity Research Journal, 10,* 175–192.

Runco, M. A. (2003). Commentary on personal and potentially ambiguous creativity: You can't understand the butterfly unless you (also) watch the caterpillar. *Creativity Research Journal, 15*, 137–142.

Sawyer, R. K. (2006). Educating for Innovation. *Thinking Skills and Creativity, 1*, 1, 41-48.

Sawyer, R.K. (2003). *Group creativity: Music, theater, collaboration*. Mahwah, NJ: Erlbaum.

Schooler, C., Mulatu, M. S., & Oates, G. (1999). The continuing effects of substantively complex work on the intellectual functioning of olderworkers. *Psychology and Aging, 14*, 483–506.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin, 86,* 420–428

Simonton, D. K. (1984). *Genius, creativity, and leadership*. Cambridge, MA: Harvard University Press

Simonton, D. K. (1990). *Psychology, science, and history: An introduction to historiometry.* New Haven, CT: Yale Univ. Press

Simonton, D. K. (1992). Leaders in American psychology, 1874–1967: Career development, creative output, and professional achievement. *Journal of Personality and Social Psychology, 62,* 5–17.

Simonton, D. K. (1997). Creative productivity: A predictive and explanatory model of career trajectories and landmarks. *Psychological Review, 104*, 66–89.

Simonton, D. K. (1999). Significant samples: The psychological study of eminent individuals. *Psychological Methods, 4,* 425–451.

Subotnik, R. F., &Steiner, C. L. (1994). Adult manifestations of adolescent talent in science: A longitudinal study of 1983 Westinghouse Science Talent Search winners. In R. F. Subotnik& K. D. Arnold (Eds.), Beyond Terman: Contemporary longitudinal studies of giftedness and talent (pp. 52–76). Westport, CT: Ableq.

Taylor, C. W., & Barron, F. (1963). *Scientific creativity: Its recognition and development*. New York: Wiley

Tebes, J. K., Irish, J.T., Vasquez, M.J.P., & Perkins, D.V. (2004). Cognitive transformation as a marker of resilience. *Substance Use & Misuse, 39*, 769-788.

Vandervert, L., Schimpf, P., & Liu, H. (2007). How working memory and the cerebellum collaborate to produce creativity and innovation. *Creativity Research Journal, 19,* 1-19.

Vincent, P.H., Decker, B.P, & Mumford, M.D. (2002). Divergent thinking, intelligence, and expertise: A test of alternative models. *Creativity Research Journal, 14,* 163-178.

Ward, T.B., Smith, S.M. and Finke, R.A. (1999) Creative Cognition. In Sternberg, R.J. (ed.)*, Handbook of creativity*. Cambridge University Press, Cambridge, 189–213.

Weisberg, R. W. (1999). Creativity and Knowledge: A challenge to theories. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 226–250). Cambridge, England: Cambridge University Press.

Zuckerman, H. (1967). Nobel laureates in science: Patterns of productivity, collaboration, and authorship. *American Sociological* Review, 32, 391–403.

Zuckerman, H. (1977). *The scientific elite*. New York: Free Press.

Zuckerman, H., & Cole, J. R. (1994). Research strategies in science: A preliminary inquiry. *Creativity Research Journal, 7*, 385–390.

Appendix A: Tables

Table 1

Correlations and Reliabilities for Model Attributes and Scientific Creativity

	1	2	3	4	5	6	7	8	9
Adversity									
1. Adverse Events	(.90)								
2. Coping Strategies	-0.03	(.91)							
3. Motivation	-0.15	*0.23*	(.90)						
4. Opportunity search	0.05	**0.30**	0.18	(.88)					
Collaborations									
5. Professional Activity	-0.20	0.16	*0.22*	0.02	(.95)				
6. Professional Relationships	**-0.30**	0.16	*0.25*	-0.12	**0.51**	(.90)			
7. Opportunities for Collaboration	**-0.35**	0.11	**0.33**	-0.10	**0.58**	**0.55**	(.90)		
8. Active Collaboration	-0.07	**0.10**	-0.04	-0.01	0.19	0.20	0.20	(.90)	
9. Participation	-0.04	0.09	0.08	0.04	*0.21*	**0.35**	**0.34**	**0.45**	(.91)
Work Strategies									
10. Prestige	**-0.41**	0.04	0.18	-0.06	**0.47**	**0.37**	**0.60**	0.10	0.13
11. Network	-0.16	-0.10	-0.13	0.20	0.06	0.03	0.09	*0.23*	0.03
12. Area Knowledge and Research	-0.18	0.23	*0.26*	0.02	0.19	**0.49**	**0.31**	*0.25*	0.11
13. General Strategies	-0.16	**0.31**	**0.30**	*0.23*	*0.27*	0.19	*0.26*	0.20	0.10
14. Core Research	**0.29**	**-0.34**	-0.09	-0.20	-0.08	**-0.30**	**-0.30**	*-0.22*	*-0.21*
15. Fringe Search	-0.08	0.19	-0.01	0.16	0.07	0.16	0.14	0.16	0.21
16. Specific Strategies	-0.04	**0.29**	**0.28**	**0.29**	-0.06	0.07	0.11	-0.13	-0.04
Scientific Creativity									
17. Social Influence	-0.03	-0.02	0.12	0.08	0.18	**0.30**	0.16	0.17	**0.30**
18. Theoretical Influence	-0.01	0.11	*0.24*	0.10	**0.30**	**0.28**	**0.43**	*0.21*	**0.33**
19. Technical Influence	0.00	0.13	0.16	-0.07	0.09	0.15	0.19	0.05	0.14
20. Groups Led	0.01	0.09	0.11	*0.22*	0.07	0.00	0.11	0.05	0.19
21. Professional Influence	-0.08	0.12	-0.05	0.17	0.16	0.11	0.12	0.05	0.07

Note: Bold indicates correlation significance at the .01 level. Italics indicate correlation significance at the .05 level.

Table 1: Continued

Correlations and Reliabilities for Model Attributes and Scientific Creativity

10	11	12	13	14	15	16	17	18	19	20
(.87)										
0.09	(.89)									
0.17	0.02	(.91)								
0.24	*0.24*	**0.39**	(.88)							
-0.17	-0.12	-0.16	-0.20	(.91)						
0.09	0.16	0.18	*0.21*	-0.10	(.87)					
-0.06	*-0.22*	*0.21*	0.20	-0.13	0.12	(.72)				
0.18	0.20	0.09	0.11	-0.19	0.00	-0.19				
0.25	-0.15	**0.34**	*0.23*	*-0.26*	0.12	0.14	0.20			
0.03	**0.30**	0.16	*0.26*	-0.20	**0.41**	-0.16	**0.30**	0.12		
0.06	0.15	0.14	0.10	-0.13	0.11	0.17	*0.22*	0.12	0.18	
0.02	0.08	-0.10	0.08	-0.06	0.13	0.08	-0.01	0.09	-0.09	-0.09

Note: Bold indicates correlation significance at the .01 level. Italics indicate correlation significance at the .05 level.

Table 2

Correlations for Controls and Scientific Creativity

	1	2	3	4	5	6	7
Controls							
1. Education							
2. Support from Organization, Peers, etc	0.08						
3. Focus on Work	-0.10	**0.29**					
4. Work in Lab	0.11	**0.31**	0.11				
5. Work in Field	-0.22	-0.17	0.08	**-0.83**			
6. Awards	0.10	**0.33**	0.22	*0.23*	-0.09		
7. Strength of Documentation	0.05	0.08	0.02	0.13	-0.13	-0.02	
Scientific Creativity							
8. Social Influence	-0.13	**0.38**	**0.39**	-0.09	0.15	-0.05	-0.02
9. Theoretical Influence	0.07	**0.30**	0.15	**0.42**	*-0.23*	*0.25*	**0.30**
10. Technical Influence	0.05	**0.34**	**0.40**	0.06	0.09	0.12	*-0.23*
11. Groups Led	*-0.25*	0.16	*0.24*	0.01	0.06	0.06	0.01
12. Professional Influence	0.12	0.01	-0.09	0.06	-0.14	0.10	0.07

Note: Bold indicates correlation significance at the .01 level. Italics indicate correlation significance at the .05 level.

Table 2: Continued

Correlations for Controls and Scientific Creativity

8	9	10	11	12
0.20				
0.29	0.12			
0.22	0.12	0.18		
-0.01	0.09	-0.09	-0.09	

Note: Bold indicates correlation significance at the .01 level.
Italics indicate correlation significance at the .05 level.

Table 3

Regressions for scientific creativity on adversity, collaborations, and work procedures

Regression Table	Social Influence	Theoretical Influence	Technical Influence	Groups Led	Professional Influence
Covariates					-
Education Level	-	-	-	-0.25	-
Support from Organization, Peers, etc	0.45	-	0.26	-	-
Focus on Work	0.32	-	0.34	-	-
Work in Lab	-	0.71	-	-	-
Work in Field	-	0.39	-	-	-
Awards	-0.26	-	-	-	-
Strength of Documentation		0.26	-0.25	-	-
R^2	**0.33**	**0.25**	**0.28**	*0.06*	
Adversity					
Adverse Events	0.05	0.10	0.02	0.05	-0.10
Coping Strategies	-0.13	0.04	0.04	0.00	0.97
Motivation	0.02	0.13	0.09	0.17	-0.12
Opportunity Search	0.16	0.02	-0.05	0.14	0.17
R^2	0.35	0.28	0.30	0.12	0.05
R^2_c	0.02	0.03	0.01	0.06	0.05
Collaborations					
Professional Activity	0.01	0.01	-0.08	0.09	0.13
Professional Relationships	0.07	0.04	-0.02	-0.09	0.01
Opportunities for Collaboration	0.03	*0.20*	0.14	0.11	0.02
Active Collaboration	-0.20	-0.06	-0.11	-0.09	0.00
Participation	0.17	**0.27**	0.08	0.17	0.03
R^2	0.36	**0.43**	0.30	0.33	0.03
R^2_c	0.04	**0.14**	0.02	0.05	0.03
Work Procedures/Strategies					
Prestige	-0.02	0.06	*-0.17*	-0.02	0.02
Network	0.06	**-0.21**	0.07	0.14	0.06
Area Knowledge and Research	0.07	**0.20**	0.05	0.07	-0.18
General Strategies	-0.04	0.02	0.12	0.02	0.08
Core Search	-0.16	**-0.18**	-0.09	-0.08	-0.04
Fringe Search	-0.10	0.01	**0.32**	0.02	0.12
Specific Strategies	-0.11	0.01	**-0.22**	0.15	0.10
R^2	0.36	**0.41**	**0.46**	0.12	0.06
R^2_c	0.04	**0.12**	**0.18**	0.06	0.06

Note: Standardized regression weights presented. Bold indicates correlation significance at the .01 level. Italics indicate correlation significance at the .05 level. Each model entered in separate analyses after controls.

Appendix B: Figures

Figure 1.
Model of Adversity and Creativity.

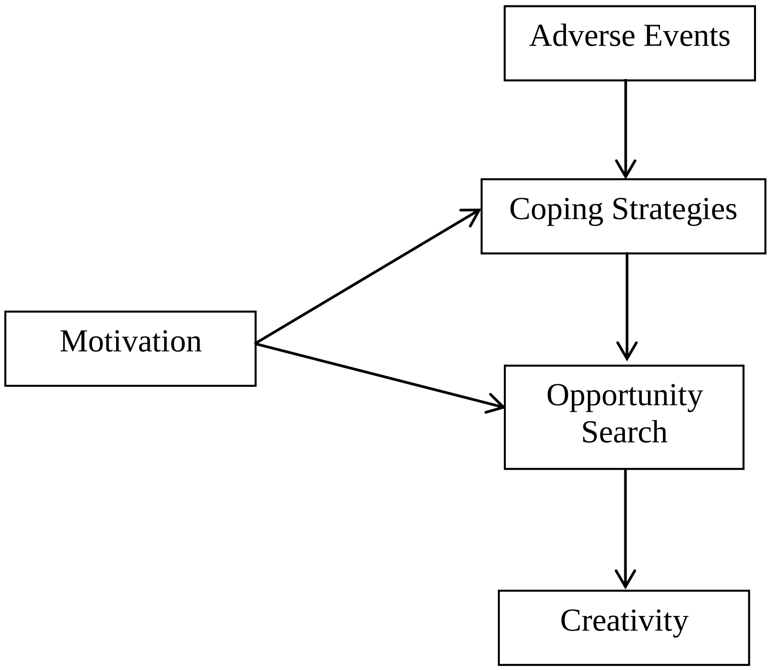

Figure 2.
Model of Collaborations and Creativity.

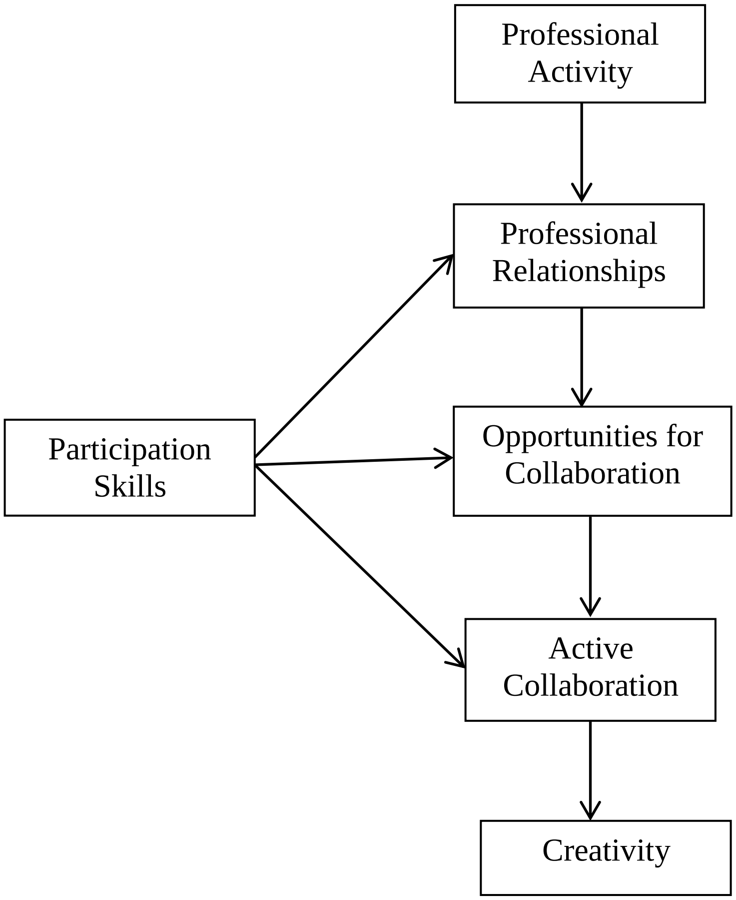

Figure 3.
Model of Work Strategies and Creativity.

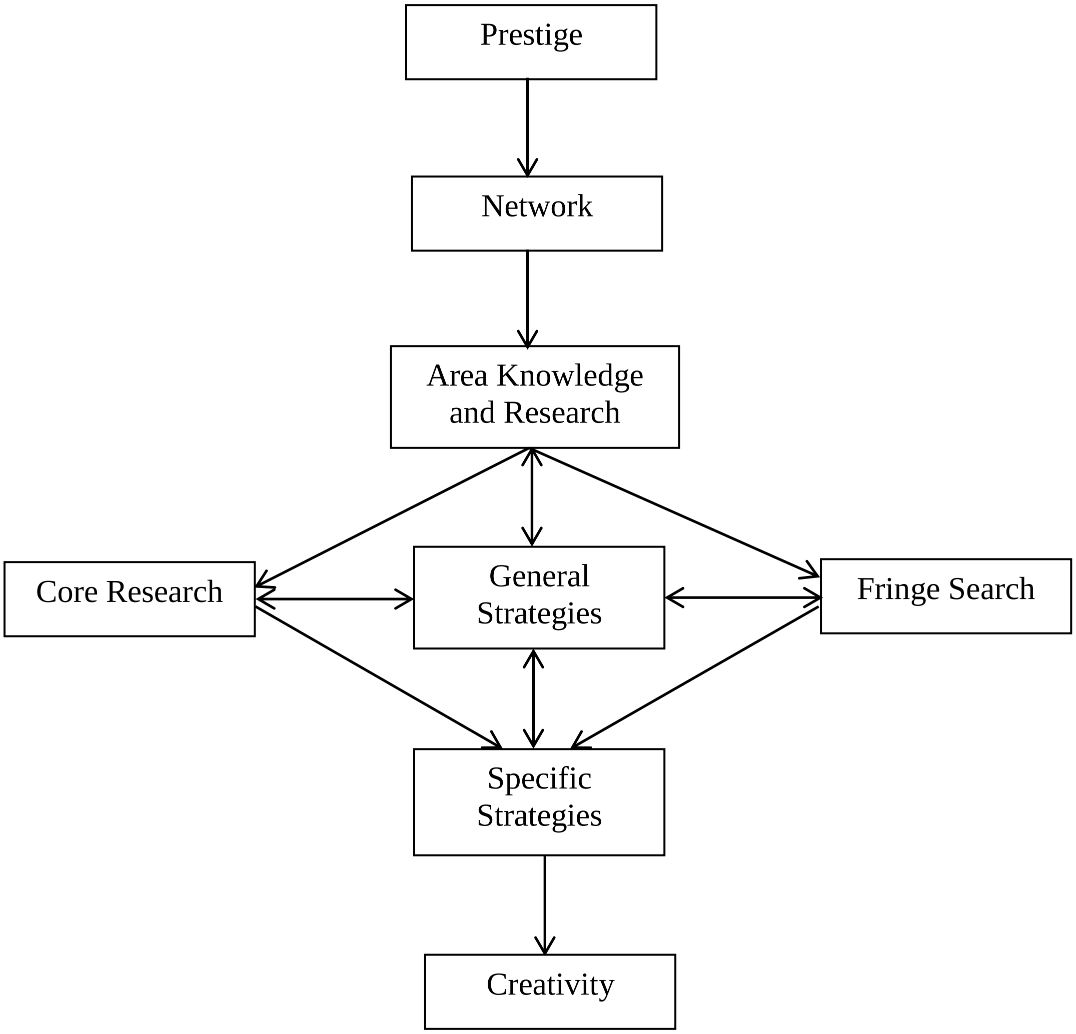

Figure 4.
Scientists and Associated Biographies

Name (Last, First)	Book Name
Adorno, Theodor	Theodor W. Adorno: One last genius
Allport, Gordon	Gordon Allport: The man and his ideas
Andrews, Roy Chapman	Dragon hunter: Roy Chapman Andrews and the Central Asiatic…
Appleton, Edward	Sir Edward Appleton
Aron, Raymond	Raymond Aron: The philosopher in history
Baade, Walter	Walter Baade: A life in astrophysics
Bailey, Liberty	Liberty Hyde Bailey: An informal biography
Bardeen, John	True genius: The life and science of John Bardeen…
Barthes, Roland	Roland Barthes: The professor of desire
Bay, Zoltan	Zoltan Bay, atomic physicist: A pioneer of space research
Beadle, George Wells	George Beadle, an uncommon farmer: The emergence of genetics…
Bell, Alexander Graham	Reluctant genius: Alexander Graham Bell and the passion for invention
Bell, Daniel	Daniel Bell
Bethe, Hans Albrecht	Hans Bethe and his physics
Bhabha, Homi Jehangir	Homi Jehangir Bhabha, 1909-1966
Bjerknes, Vilhelm Frimann	Appropriating the weather: Vilhelm Bjerknes and the construction of…
Blackett, Patrick	Patrick Blackett: Sailor, scientists, and socialist
Boas, Franz	Franz Boas
Bohr, Niels	Harmony and unity: The life of Niels Bohr
Bok, Bart	The man who sold the milky way: A biography of Bart Bok
Bowlby, John	John Bowlby: His early life
Bowman, Isaiah	The life and thought of Isaiah Bowman
Braun, Wernher von	Wernher von Braun: The man who sold the moon
Bruner, Jerome	Jerome Bruner: The cognitive revolution in educational theory
Bunau-Varilla, Phillipe-Jean	Phillipe-Jean Bunau-Varilla: The man behind the Panama Canal
Burbank, Luther	A gardener touched with genius: The life of Luther Burbank
Carrel, Alexis	The immortalists: Charles Lindbergh, Dr. Alexis Carrel, and their daring…
Chadwick, James	The neutron and the bomb: A biography of Sir James Chadwick
Chain, Ernst	The life of Ernst Chain: Penicillin and beyond
Coase, Ronald	Ronald Coase
Cockcroft, John	Cockcroft and the atom
Crawford, OGS	Bloody old britain: OGS Crawford and the archaeology of modern life

Crick, Francis	Francis Crick: Discoverer of the genetic code
Curie, Marie	Obsessive genius: The inner world of Marie Curie
De Forest, Lee	Electronics pioneer: Lee De Forest
Dewey, John	The education of John Dewey: A biography
Dubos, Rene Jules	Rene Dubos: Friend of the good earth
Einstein, Albert	Albert Einstein: A biography
Fermi, Enrico	Enrico Fermi: His work and legacy
Fleming, Alexander	Penicillin man
Foucault, Michel	The lives of Michel Foucault
Franklin, Rosalind	Rosalind Franklin: The dark lady…
Freud, Anna	Anna Freud: A biography
Godel, Kurt	Logical Dilemmas: The life and work…
Gramsci, Antonio	Antonio Gramsci
Hawking, Steven W.	Stephen Hawking: A life in science
Hubble, Edwin	Edwin Hubble: The discoverer of the big…
Innis, Harold	Marginal man: The dark vision of Harold Innis
Jacobs, Jane	Urban visionary
Jensen, Arthur	Arthur Jensen
Jordan, David Starr	David Starr Jordan: Prophet of freedom
Keynes, John Maynard	John Maynard Keynes: A personal biography…
Kinsey, Alfred	Kinsey: A biography
Lawrence, Ernest	Lawrence and his laboratory: A history of…
Lockyer, Joseph	Science and controversy: A biography of Sir Norman…
Mannheim, Karl	Karl Mannheim: The development of his thought
Marconi, Guglielmo Marchese	Thunderstruck
Mauss, Marcel	Marcel Mauss: A Biography
Mawson, Sir Douglas	Douglas Mawson: The life of an explorer
McLuhan, Marshall	Escape into understanding
Mead, George H.	The making of a social pragmatist
Meitner, Lise	Lise Meitner: A life in physics
Milgrim, Stanley	The man who shocked the world
Mills, C. Wright	An american utopian
Mincer, Jacob	A founding father of modern labor economics
Murray, Henry A	Love's story told: A life of Henry A. Murray
Myrdal, Alva	Alva Myrdal: The passionate mind

Neumann, John von	The scientific genius who pioneered the modern computer...
Oppenheimer, Robert J.	American prometheus: The triumph and tragedy of J. Robert Oppenheimer
Park, Robert E.	Robert E. Park: Biography of a sociologist
Parsons, Talcott	Talcott Parsons
Pavlov, Ivan Petrovic	Ivan Pavlov
Perls, Fritz	Fritz
Perutz, Max	Max Perutz and the secret of life
Porter, Russell	Russell W. Porter: Arctic explorer, artist, telescope maker
Rank, Otto	Acts of will: The life and work of Otto Rank
Richards, Ivor Armstrong	I.A. Richards: His life and work
Robbins, Lionel	Lionel Robbins
Rostow, Walt	America's Rasputin: Walt Rostow and the Vietnam War
Russell, Bertrand	Bertand Russell: A life
Sagan, Carl	Carl Sagan: A life
Salam, Abdus	Abdus Salam: A nobel laureate from a Muslim country
Tarski, Alfred	Alfred Tarski: Life and logic
Teller, Edward	Edward Teller: A giant of the golden age of physics
Tesla, Nikola	Tesla: Man out of time
Volcker, Paul	The making of a financial legend
Watson, JB	Mechanical man: Joan Broadus Watson and the beginnings of behaviorism
Watson-Watt, Robert	The radar man
Webb, Beatrice	The socialist with a sociological imagination
Wells, Ida B.	To keep the waters troubled
Wiley, Harvey	Politics and purity
Woolley, Leonard	Woolley of Ur: The life of Sir Leonard Woolley
Zermelo, Ernst	Ernst Zermelo: An approach to his life and work

Figure 5.
Example Rating Scales for Control variables.

Time on Projects – Average amount of time scientist worked on projects

1	2	3	4	5
Days	Weeks	Months	1-5 Years	6 or more years
e.g. on average, only spent days on projects		e.g. on average, scientist spent months working on projects		e.g. on average, scientist spent more than 6 years on projects (long-term)

Project Support – Amount of project support scientist received from organization, field, peers, superiors, etc (funding, encouragement, backing, help/collaboration, etc)

1	2	3	4	5
Scientist had little to no project support		Scientist had some support for project		Scientist had a high level of support for project
e.g. no funding for project		e.g. scientist's organization encouraged his/her work and offered some funding		e.g. fully funded, peers encouraged scientist and helped, organization backed him/her, etc.

Figure 6.
Example Rating Scales for Adversity, Collaborations, and Work Strategies.

Motivated Even When Facing Failure (Adversity) – Degree to which scientist remains motivated even when faced with failure

1	2	3	4	5
Scientist is not motivated when facing failure/when he/she has failed		Scientist expresses some motivation when faced with failure		Scientist expresses strong motivation even when faced with failure
e.g. gives up on project when it is not successful		e.g. continues some work on failed project, although they are less involved/dedicated		e.g. continues working on failed projects with the same intensity and involvement

Position Visibility (Collaborations)– Degree to which scientist's position is visible (made known, apparent, etc) to others

1	2	3	4	5
Scientist's position is not visible to others		Scientist's position is somewhat visible to others		Scientist's position is very visible to others
e.g. "silent" position; not public		e.g. mentioned by organization in passing, not outwardly expressed		e.g. awards given publicly, sent to conferences because of the position, etc.

Multiple Areas (Work Strategies)– Degree to which scientist was involved in more than one area of work, study, etc.

1	2	3	4	5
Scientist was involved in only one area		Scientist was somewhat involved in more than one area		Scientist was involved in more than one area of work
e.g. his/her primary field only		e.g. did some nonessential work in a secondary field or several secondary fields		e.g. had multiple primary fields; lots of work done in secondary field(s)

Figure 7.
Example Rating Scales for Scientific Creativity.

Theoretical Influence – Degree to which scientist influenced the theoretical work in the field

1	2	3	4	5
Scientist had minimal impact on theoretical field		Scientist had moderate impact on theoretical field		Scientist substantial impact on theoretical field
e.g. did not engage in academic work		e.g. conducted some academic research based on theory		e.g. published several academic papers involving theory; developed or significantly added to theoretical work in field

Technical Influence – Degree to which scientist influenced the technical work in the field

1	2	3	4	5
Scientist had minimal impact on technical field		Scientist had moderate impact on technical field		Scientist substantial impact on technical field
e.g. did not engage in technical work		e.g. engaged in a some work with direct practical, real-world applications		e.g. worked primarily on projects involving specific field applications; developed new work procedures, invented new technologies