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How Development and Personality Influence Scientific Thought, Interest, and Achievement

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In the present article, I review and summarize two subdisciplines of the psychology of science, namely development and personality. In the first section concerning developmental psychology of science, I review three major developmental topics: 1) the literature on the developmental and familial influences behind scientific interest and scientific talent (e.g., birth-order and theory acceptance, immigrant status and scientific talent); 2) gender and scientific interest and talent; and lastly, 3) age and scientific interest and productivity. In the second section concerning personality psychology of science, I organize the review around four major topics: 1) which traits make scientific interest in general more likely; 2) which traits make interest in specific domains of science more likely (especially social and physical science); 3) which traits make different theoretical orientations more likely; and finally, 4) which traits make scientific achievement and creativity more likely. From the empirical evidence reviewed, it is quite clear that developmental and personality factors impact directly and indirectly scientific thought, interest, and achievement.

Keywords: psychology of science, development, personality, mathematics, talent

To think of a scientist who appears full-blown as a scientist without a developmental path behind him or is to think the unimaginable. Likewise, imagining a scientist without a unique style of behaving and thinking is nearly impossible. Scientific interest and achievement have fascinating and complex developmental paths and are more likely to come from people with particular kinds of personalities and traits than with other kinds of personalities. In this paper, I provide an overview and summary of the current empirical literature on two subdisciplines in the psychology of science, namely development and personality psychologies of science.[1]

Developmental Psychology of Science

Developmental psychology of science is one of the most vibrant and active disciplines in the psychology of science. For example, the study and theorizing of cognitive development have many important implications and applications to a well-formed psychology of science. Jean Piaget, for instance, was a key figure in investigating and conceptualizing how cognitive processes develop, change, and maintain over the lifespan (Inhelder & Piaget, 1958; Piaget, 1952, 1972). As important of a figure as Piaget has been to the field of cognitive development, there have been important developments since Piaget, some of which are consistent with Piaget's work and some of which are not. In this section, I review three major topics in the field of developmental psychology of science: birth-order and theory acceptance, gender and development of scientific interest, and developmental paths to scientific eminence (i.e., age and scientific interest and productivity).

How do talented children become scientists of the first order? Family environments, which can either facilitate or hinder development of

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[1] For sake of space, one developmental topic I leave for another publication is the evidence for and theory on how children use first principles in distinct domains of thought and can be viewed very much as implicit (folk) psychologists, physicists, biologists, and mathematicians (see Feist, 2006; Feist & Gorman, 1998; Klahr, 2000; Zimmerman, 2000).

scientific interest and talent, clearly play an important role in shaping and guiding such interest and talent. There are numerous influences from the early home environment that can have these effects, but the four that I review are birth-order and theory acceptance, immigrant-status, gender, and age and productivity.

Birth-Order and Theory Acceptance

In his book *Born to Rebel,* Frank Sulloway (1996) makes a persuasive case that birth-order is a fundamental influence on an individual's disposition to accept or reject authority, whether it be familial, educational, political, social, or scientific. The fundamental finding, one that he puts in the context of evolutionary theory of sibling rivalry and competition for resources, is that firstborns are disposed toward accepting the power structure they are born into, because they are the oldest, strongest, and most identified with the authority of their parents. Due to their temporary only-born status, they once garnered all the parental resources of attention and care, so when siblings come they are then thrust into positions of responsibility and power. Laterborn children, on the other hand, are inherently disposed toward questioning and challenging the innate power structure of the family, given their built-in inferior status within the family.

What makes Sulloway's argument persuasive is his extensive historical documentation and systematic testing of the basic hypothesis that firstborn individuals are more likely to accept intellectually and politically conservative theories and/or revolutions, whereas laterborn individuals are more likely to support liberal theories and/or revolutions. From the perspective of the psychology of science, most relevant is Sulloway's detailed analysis of revolutionary theory acceptance in the history of science, mostly focusing on Charles Darwin's theory of evolution by natural selection, but also on Copernicus's heliocentric theory as well as dozens of other radical, technical, or conservative theories in the history of science. To give but a few examples of many: laterborns were 4.6 times more likely than firstborns to accept Darwin's theory of natural selection in the sixteen years after it was first published than firstborns. They were also almost ten times as likely to accept evolutionary theory prior to Darwin and more than five times as likely to accept Copernicus' sun-centered theory. On the other hand, firstborns were more likely than laterborns to endorse and support conservative scientific theories, such as vitalism or eugenics. Perhaps an even more telling finding is the fact that creative-revolutionary thinkers themselves, at least in the ideological revolutions of Copernicus and Darwin, are more likely to be laterborns than firstborns. No such effect held for technical revolutions (e.g., Newton, Einstein, Quantum theory), or conservative theories (e.g., vitalism, idealist taxonomy, or eugenics).

Immigrant Status and Scientific Interest and Talent

One of the more interesting findings predicting scientific interest and talent has been immigrant status, specifically being from a family that is within two generations of immigrating to the U.S. A disproportionate number of science majors, scientists, and elite scientists had at least one parent who was new to this country. By disproportionate I mean upwards of 40% when only about 12% of the U.S. population in 2005 is first generation (foreign-born) American (Berger, 1994; Camarota, 2005; Feist, in press; Helson & Crutchfield, 1970; Portes & Rumbaut, 2001; Simonton, 1988a). For instance, in a study of elite scientists, Feist (in press) recently reported that 20 out of 55 (36%) Westinghouse Science Fair finalists had a father and 22 out of 55 (40%) had a mother either born elsewhere or were first generation Americans. The Westinghouse competition, as it was known until 1998 (now it is the Intel competition), is the oldest and most prestigious science competition for high school students. Similarly, in a sample of members of the National Academy of Sciences, 28 of 85 (33%) had fathers and 29 (34%) had mothers who were immigrants or first generation Americans (Feist, in press). Membership in the National Academy ranks second only to the Nobel Prize in prestige (Cole & Cole, 1973; Feist, 1997). What makes these figures all the more remarkable is that, in general, the foreign-born population in the U.S. is poorer and less-well educated than the native population (Camarota, 2005). One inference, therefore, is that a particular subset of immigrants or immigrant children appears to use math, science, and technology careers as a way out of poverty.

Families who recently come to the shores of the U.S. may well foster a particular set of values that encourages and maybe even demands high level achievement, whether it be in science, medicine, or business. As suggested by classic work in the sociology of science, an interesting speculation on this phenomenon is that science may be more meritocratic than most other career paths and therefore talent and achievement in and of itself is more likely to be recognized and rewarded (see Cole & Cole, 1973; Merton, 1973). A significant scientific finding is perhaps more likely to be evaluated on its own merits than novel business or political ideas. Immigrant families may realize this, and, given that fluency in the native language may not be as critical as it is in other careers, parents may therefore encourage their children to go into math, science, or engineering careers.

Simonton (1988b) offers another possible explanation: "Individuals raised in one culture, but living in another are blessed with a heterogeneous array of mental elements, permitting combinatory variations unavailable to those who reside solely in on cultural world" (p. 126). Having been an exchange student in high school myself, I can personally attest to the power of simultaneously having two cultural lenses through which to compare experiences. By being exposed to a different way of doing things and a different way of thinking, one's own implicit assumptions are more obvious and one takes less for granted what one believes, that is, without reflection.

And reflection and explicit thought is, as the developmental psychologist Annette Karmiloff-Smith (1992) has made clear, a fundamental feature of cognitive development. With development, thinking becomes more and more explicit and therefore more flexible and manipulatable. Moreover, this is precisely what metacognition is—being aware of and being able to think about one's thinking (Flavell, 1979; Sperber, 1994; Sternberg, 1985). Highly intelligent and gifted students do tend to have higher metacognitive skills than less intelligent and gifted students (Chan, 1996; Schwanenflugel, Stevens, & Carr, 1997; Shore & Dover, 1987). And yet metacognition can be learned. A significant body of literature now exists demonstrating the effectiveness of teaching metacognitive skills in helping students to better understand mathematical and scientific concepts and, therefore, to think more scientifically (Despete, Roeyers, & Buysse, 2001; Georghiades, 2000; Glynn & Muth, 1994; White & Frederiksen, 1998).

Scientific reasoning and hypothesis testing require just such a distancing between one's thoughts and the evidence for them. Kuhn and her colleagues have argued that the coordination of theory and evidence is the *sine qua non* of scientific reasoning (Kuhn, 1989, 1993; Kuhn & Pearsall, 2000; Kuhn, Amstel, O'Loughlin, 1988): "Accordingly, the development in scientific thinking believed to occur across the childhood and adolescent years might be characterized as the achievement of increasing cognitive control over the coordination of theory and evidence. This achievement, note, is metacognitive in nature because it entails mental operations on entities that are themselves mental operations" (Kuhn & Pearsall, 2000, p. 115).

In short, being first or second generation can for some make quite clear what their assumptions are and, by so doing, make reflective and metacognitive thinking more likely. These cognitive abilities, in turn, facilitate scientific interest and reasoning. So by being bicultural, a person grows up with quite a cognitive advantage, one that in the end makes him or her more likely than others to be interested in and have talent for science.

Gender and Development of Scientific Interest

One of the more entrenched influences on the development of scientific interest appears to be gender. As Evelyn Fox Keller (1985), among others, has pointed out, the history of science is replete with associations, both implicit and explicit, between science and men; male scientists historically have tried to "tame" or "control" the feminine "Mother Nature" (Fox Keller, 1985; cf. Nosek, Banaji, & Greenwald, 2002).

There is empirical evidence that supports some gender differences in interest in science or math, whether it comes in the form of explicit attitudes (Eccles, 1987; Hyde, Fennema, Ryan, Frost, & Hopp, 1990), implicit attitudes (Nosek et al., 2002), performance on aptitude tests (Benbow & Stanley, 1983; Benbow & Lubinski, 1993; Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000; Geary, 1998; Halpern, 2000) or actual graduation and career data (Cole, 1987;

Cole & Zuckerman, 1987; Farmer, Wardrop, & Rotella, 1999; Jacobwitz, 1983; National Science Foundation [NSF], 1999; O'Brien, Martinez-Pons, Kopala, 1999; Reis & Park, 2001; Subotnik, Duschl, & Selmon, 1993). The general conclusion from this body of research is that men are more likely than women to view science positively and be more interested in science and math as a career. This is true when both men and women view themselves as "the science type," but even more so when they do not (Feist, Paletz, and Weitzer, 2005). Moreover, although there is no overall gender difference in intelligence, there does appear to be some systematic differences in the mathematical domain (males being both higher and lower than females) and in the verbal domain (females being higher; Benbow & Stanley, 1983; Geary, 1998; Halpern, 2000; Kimura, 1999; Stumpf & Stanley, 2002).

There are, however, at least two important qualifications to these generalizations. First, gender differences are less apparent in childhood and adolescence than adulthood, which has been referred to as an "inverted funnel" effect; second, gender differences are less apparent in the social sciences than in the physical sciences, with biological sciences being in the middle.

Regarding the inverted funnel phenomenon, in terms of courses taken, the "gender gap" in science is not evident at the high school or undergraduate level or in the social sciences. High school male and female students were equally likely to take advanced math courses (trigonometry and calculus) and almost as likely to take advanced science courses (biology, chemistry, and physics). In advanced science courses, there were a slightly higher percentage of females taking biology and chemistry and a slighter higher percentage of males taking physics. As students progress through their academic careers, however, there is an increasing gender disparity in interest in science and math (Long, 2001; NSF, 1999; Rosser, 1988; Subotnik et al., 1993). At the undergraduate level, the percentage of women who earned science or engineering degrees in 1995 was 46 percent (after being about 38 percent ten years earlier). At the graduate level, a more obvious gender gap exists, even in the biological and social sciences, with 39 percent of the masters degrees in science and engineering and 33 percent of the doctoral degrees in science and engineering being awarded to women. And finally in terms of career, the disparity widens even more, with only 4 to 6 percent of the full professors in science and math being women (NSF, 1999).

The most extreme gender difference is seen at the most elite level (Long, 2001). On average, only two percent of the members of the National Academy of Sciences are female. Similarly, Feist (in press) found that although, compared to norms, male and female Westinghouse finalists were much more likely to earn PhDs or MDs (upwards of 80%), female finalists were more likely than the male finalists to move away from science in terms of training and career. This finding is the same that Subotnik reported with the 1983 Westinghouse semifinalists (Subotnik & Steiner, 1994), as well as with the study of mathematically precocious youth (Webb, Lubinski, & Benbow, 2002). It is important to note, as Webb and colleagues (2002) have recently, that just because women may opt out of science-oriented careers does not mean they opt out of productive and achieving careers.

The second qualification concerning gender and science is that not all fields of science are equally gender biased in their distributions. Unequal distributions are most striking in the physical sciences, less striking in the biological sciences, and least striking in the social sciences. Only 17 percent of the engineering degrees and 35 percent of both the mathematics and physical-earth science degrees were awarded to women, whereas nearly 50 percent of the biological and social science degrees, and 73 percent of the psychology degrees were awarded to women in 1995 (NSF, 1999). Similarly, Long's (2001) analysis of trends in national samples showed that from 1973 to 1995 women went from being 2 percent to 12 percent of the engineering PhD graduates and from 21 percent to 51 percent of the social-behavioral science PhD graduates. All other scientific fields were in between these two ends of the continuum. In addition, in a sample of mathematically precocious students who immediately after high school said they intended to major in math or science, five years later men were more likely to have received engineering and physical science degrees and women more likely to have received biological science and medical science degrees (Webb et al., 2002).

The gender gap, however, does seem to be narrowing somewhat compared to 30 years ago. For instance, the most exhaustive and extensive study of PhD scientists over a twenty-two year period (1973 to 1995) by the National Research Council has documented progress but not yet equality for women in science (Long, 2001). When the appropriate controls (such as rank, field, and institution) are made, the gender disparity is not so extreme, but it still exists. For instance, men hold a fourteen percentage-point advantage in holding tenure-track positions, but this difference approaches zero once career age is held constant. This suggests that the gender disparity in tenure-track science positions should continue to decline as more and more women become eligible. Also, salary differences diminish once rank is controlled for, but they do not disappear completely, suggesting that men do get paid a bit more for the same position. Similarly, Feist (in press) reported a significant increase in the percentage of female Westinghouse finalists from 1965 to 1995.

In addition, marriage and family does affect men and women rank and productivity differently, but not necessarily in the manner one might expect. Long (2001), for instance, reported that women who interrupted their careers for marriage and family in 1979 were less likely to obtain a tenure-track position, but there was no effect in 1995. For men, on the other hand, the effect of getting married and having children had a positive effect on productivity and this effect increased between 1979 and 1995.

If the fact that some gender differences do exist (at least later in life and in the physical sciences) is relatively agreed upon, the explanation and cause of these differences remain unclear and controversial. Insight into the origins of the gender difference in scientific interest comes from a study by Crowley, Callanan, Tenenbaum, and Allen (2001). In samples of children ages 1 to 8, they found that there was a gender difference in frequency with which parents provided explanations (causal, correlational, or analogical) versus mere descriptions of the exhibits on a visit to a local science museum. Parents were more likely to provide explanations to boys and descriptions to girls. The explanation rates were about 29% for boys and about 9% for girls. Explanations, of course, provide more complex reasoning about how things work and why and therefore are more likely to engage the child's interest and curiosity. These results suggest that already at a young age, parents may be treating boys and girls differently in science.

Another set of possible explanations were proposed in 2005 by Harvard President Lawrence Summers in his now infamous talk at a conference on women in science. In order of priority, he hypothesized that high-powered competitive jobs that require 80 hours a week are less suited to women's lifestyles, that "intrinsic aptitude" differences might exist between women and men, and differences in socialization and discrimination discourage women from pursuing careers in science. The one that started the firestorm was the "intrinsic aptitude" hypothesis. In making his argument, Summers primarily focused on the differences in standard deviations between men and women, with men being disproportionately represented at the low and high ends of many aptitude tests, especially in math and science. Here is a crucial excerpt from his speech:

> So my best guess, to provoke you, of what's behind all of this is that the largest phenomenon, by far, is the general clash between people's legitimate family desires and employers' current desire for high power and high intensity, that in the special case of science and engineering, there are issues of intrinsic aptitude, and particularly of the variability of aptitude, and that those considerations are reinforced by what are in fact lesser factors involving socialization and continuing discrimination. I would like nothing better than to be proved wrong, because I would like nothing better than for these problems to be addressable simply by everybody understanding what they are, and working very hard to address them (Summers, 2005).

In March of 2005, hundreds of mostly unfavorable and critical responses to Summer's comments were published in newspapers and magazines around the country. One of the more sympathetic ones was written by Joan Ryan of the *San Francisco Chronicle,* and it focused on an interview Ryan had with University of California at San Francisco psychiatrist Louann Brizendine, who is finishing up a book entitled *The Female Brain*. Here is an excerpt:

> I wanted to know if [Brizendine] bought into the argument that "intrinsic aptitude"—Summers' phrase—keeps women out of the top tiers of science and engineering. Yes, she said, but not in the simple way Summers suggests. It has nothing to do with the aptitude of men and women. It's all about the aptitude of boys and girls, she said. The difference is in the circuitry and the time line on which it develops. Dif-

> ferent abilities emerge at different ages for boys and girls. Girls, Brizendine explained, develop language skills earlier than boys do; boys develop visual and spatial skills earlier than girls. By 2 1/2, many girls are actively choosing not to play with boys, not for any cultural or sociological reason but because boys have not yet grasped the concept of verbal give-and-take. Boys, with their faster-developing spatial skills, are more likely to gravitate to building blocks and train sets and physical activities that require minimal verbal interaction. (And they are more likely to find themselves in altercations because they have poor external language to hammer out a solution and poorer internal language to mediate their impulses.) (Ryan, 2005).

Brizendine then went on to discuss how by high school the brain differences have for the most part dissipated and "their brains catch up to each other." But due to their histories up to that point of developing different aptitudes, there is an educational inertia where boys tend to stay in the spatial-mechanical domains and girls more in the verbal-linguistic domains. In short, there are perhaps some "intrinsic differences" that biologically speaking narrow but sociologically speaking widen with development.

Developmental Paths to Scientific Interest and Achievement

For those who go on to become scientists, when do they know that science is the career for them? For those who do not go into science, was there a time when science was interesting to them? Finally, if a child expresses prodigious talent for science before their teen years, are they likely to actually become a scientist and, if so, are they likely to make significant contributions to the discipline? Moreover, how to what extent does publishing early foreshadow a lifetime of scientific productivity? These are the central questions involving the development of scientific interest and talent.

Age and scientific interest and talent. A few researchers have addressed the question of who is likely to make significant contributions to science and if so did they show early signs of their talent. Feist (in press), for instance, examined the development of scientific interest in Westinghouse finalists and members of the NAS. For Westinghouse finalists, both men and women knew science was for them at an equally young age (males: M age = 11.12; females: M age = 12.20). Members of the National Academy also developed an interest in science at a very early age, with 25% knowing they wanted to be a scientist by age 14, 50% knowing by age 18, and 75% knowing by age 20. In terms of first realizing they had talent for science, 25% of the NAS members realized their talent by age 13, 50% by age 16, and 75% by age 21. The range was ages 5 to 33. Finally, NAS members began doing science early, with 75% having participated in formal research by age 21 (mean age = 19.2; median age = 20.0), and no gender difference between men and women. Half of the NAS members had published a scientific article by age 23, and at least one member had published by age 16. Those who go on to have real talent in science as adults seem to realize at a young age that they want to become a scientist (on average by age 12 for Westinghouse finalists and by age 18 for NAS members). Given that most college students change their major many times during their four years as an undergraduate, to have a group know by the end of high school or before that a particular career is right for them is quite remarkable. Early and clear insight into one's career calling is often an indicator that one knows where one's talents lies, and indeed such "crystallizing experiences" are frequently seen in adolescents who go on to be our most creative adults (Cameron, Mills, & Heinzen, 1995; Freeman, 1999; Gardner, 1993).

Age and scientific productivity. The oldest and most established question concerning the development of scientific productivity is of growth curves and publication rates, that is, how productivity (i.e., publication rates) changes with age. The findings have converged on the conclusion that the relationship between age and productivity in science (and other professions) is an inverted-U (Bayer & Dutton, 1977; Cole, 1979; Dennis, 1956; Diamond, 1986; Horner, Rushton, & Vernon, 1986; Lehman, 1953, 1966; Over, 1982, 1989; Simonton, 1988a, 1988b, 1991; Zuckerman, 1996). Further, once controls are made for different ways of operationalizing output, the curve peaks around 20 years into one's career, usually in one's early 40s. To graphically model this relationship, Simonton has developed one of his better-known differential equations, with the peak occurring roughly 20 years into one's career and thereafter slowly declining (Simonton, 1988b). However, it does peak somewhat differently for various disciplines (earlier in math and physics, later in biology and geology).

More recently, in a study of National Academy of Science members, Feist (in press) reported three unconditional growth curve models that were constructed to test Simonton's curvilinear model of age and productivity (Simonton, 1988b), namely a linear model, a quadratic model, and a cubic model. Each model provided a close fit to the data, suggesting that publication rates increase over time. Out of the three models, however, the curvilinear model provided a better fit than the linear model, and the cubic model a better fit than the curvilinear model. In other words, a model with two peaks (approximately 20 years into one's career and then again at the very end) was the best model of age and productivity (see Figure 1). A conditional model was then tested, in which age of first publication was used to predict the intercepts and growth curve trajectories of each model. Age of first publication did predict the midpoints (intercepts) in each model, but not the trajectories. Such findings suggest that those who start publishing earlier compared with later do have higher publication means at the midpoints in their career (time = 0), but do not have different, linear, quadratic, or cubic trajectories. These results are quite consistent with Simonton's curvilinear model where the peak tends to occur approximately 20 years into one's career, with a gradual decline thereafter (Simonton, 1988a, 1988b, 1991). The current results, in fact, support another phenomenon reported by Simonton, namely an end of life "swan-song" effect (Simonton, 1990). In the sample of NAS scientists, a cubic model with a second peak toward the end of one's career did a better job of explaining the data than did the single peak (curvilinear) model.

Simonton has developed a complex theoretical model that attempts to predict and explain this age-productivity relationship by focusing on intrinsic factors, namely cognitive components (Simonton, 1988a, 1988b, 1991). His theory is based on his notion of "chance-configuration" and consists of a few key assumptions: First, each creator starts off with a set amount of creative potential (number of contributions made over a normal, unrestricted life span); second, the actualization of creative potential can be broken down into two components, ideation and elaboration. Ideation is the rate at which potential ideas are expressed, whereas elaboration is the rate at which ideas are put into concrete, public form. So, as each creator pro-

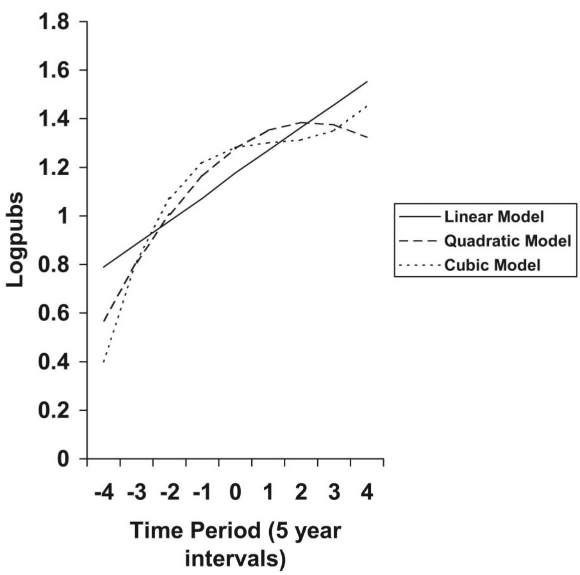

Figure 1. Growth Curve Models of Scientific Productivity. In Feist (in press). The development of scientific talent in Westinghouse finalists and members of the National Academy of Sciences. *Journal of Adult Development*, Fig. 1. Copyright Springer Publishing. Reprinted with kind permission of Springer Science and Business Media.

duces a new work she or he "uses up" some creative potential. The rate at which a creator actualizes potential and produces works is a direct function of the two cognitive transformations, ideation and elaboration.

Related to age and productivity, there is the question of whether early recognition of talent and producing works early in life predicts later levels of productivity. The empirical consensus is that early levels of high productivity do regularly predict continued levels of high productivity across one's lifetime (Cole, 1979; Dennis, 1966; Helson & Crutchfield, 1970; Horner et al., 1986; Lehman, 1953; Over, 1982; Reskin, 1977; Roe, 1965; Simonton, 1988a, 1991). Those who are prolific early in their careers tend to continue to be productive for the longest periods of time.

Lastly, there is also the question of whether the age at which one's talent for science is first expressed predicts lifetime achievement in science. Regarding age of recognized talent, Feist (in press) predicted that in a sample of NAS members, age of talent should predict age of publishing and obtaining the PhD, which in turn should predict productivity and impact. Results showed that the four precocity variables were modestly positively correlated with age of first publication, which is an intermediate variable between precocity and achievement. In other words, the younger NAS members were when they and others recognized their scientific talent, when they wanted to be a scientist, and when they first conducted scientific research, the younger they were when they published their first paper. Age of first publication in turn predicted total publication rate over the lifetime, meaning that the earlier one publishes, the more productive one will be. This pattern of relationships—from precocity to age of first publication to lifetime productivity—implies an indirect connection between precocity and publication rate. The only precocity variable that reached the .05 level of significance with lifetime productivity was age that one first conducted formal research.

Personality Psychology of Science

In addition to developmental psychology, another field of psychology of science that is moderately active is personality psychology. Personality psychology of science focuses in general on the personality traits and dispositions that predict scientific interest and scientific talent and how these traits continue to exert their influence over the course of the lifespan. There are at least four topics that have garnered enough empirical support to review and summarize: which traits make scientific interest in general more likely; which traits make interest in specific domains of science more likely (especially social and physical science); which traits make different theoretical orientations more likely; and, finally, which traits make scientific achievement and creativity more likely. Before getting into a review of these literatures, I first need to set the stage with a brief overview of the function of traits. The functional-interactionist view lays out the mechanism by which personality is related to behavior, in this case, scientific behavior, interest, and achievement.

Functional-Interactionist View of Traits

To cite Gordon Allport's famous phrase: "Personality *is* something and *does* something." (Allport, 1937, p. 48). What it is and does is directly affect behavior. In response to the infamous "person-situation debate" (Block, 1977; Epstein, 1979; Kenrick & Funder, 1988; Mischel, 1968; Nisbett & Ross, 1980), which contrasted personality and situational forces as competing explanations of behavior, many personality psychologists have recently developed a functional-interactivist theory of traits (Eysenck, 1990; Feist, 1999; Funder, 1991; Mischel & Shoda, 1999; Rosenberg, 1998). The functional perspective maintains that traits function to lower behavioral thresholds, that is, make particular behaviors more likely in given situations; in short, they raise conditional probabilities (Mischel & Shoda, 1999). The primary function of traits, therefore, is to lower thresholds for trait congruent behavior (Brody & Ehrlichman, 1998; Ekman, 1984; Eysenck, Mogg, May, Richards, & Mathews, 1991; Rosenberg, 1998). For instance, if a person has the traits of "warm and friendly," this means that in any given situation she is more likely to act in a warm and friendly manner than someone who does not possess that trait. Her threshold for behaving in a friendly manner is lower than if she did not have that trait. Moreover, there are particular situations, such as on meeting a new person or being in a group of people, where behaving this way is most likely. That is, in certain situations, traited behaviors are most likely for particular people. The function of traits is they raise (or lower) the conditional probability of a given behavior in a given situation.

As social-cognitive theorists, such as Bandura and Mischel, have argued, to understand how a person behaves in a particular situation requires an interactionist approach (Bandura, 1986; Mischel & Shoda, 1999). Specifically, there are three main components that exert bi-directional influence on each other: Person, Behavior, and Environment (Bandura, 1986; Eysenck, 1990; Mischel & Shoda, 1999). Bandura has presented perhaps the clearest model of how these three components all are both causes and effects of each other. Behavior results from both environmental and personal characteristics, but environments are created by people acting in particular ways. Furthermore, personal characteristics, whether they are attitudes such as self-efficacy or traits, result from a person behaving consistently in a particular situation.

The functional-interactionist model of personality is quite useful in interpreting and explaining the personality findings on scientific behavior, interest, and talent. That is, certain personality traits do make interest in and talent for science more likely. What are they?

Personality and Scientific Interest

The first step toward being a scientist is simply having an interest in one form of science or another. As it turns out, personality dispositions have something to do with whether one becomes interested in science as a career choice or not. In 1998, I published a quantitative review of the literature on personality and scientific interest and creativity (Feist, 1998). In this meta-analytic review of which personality traits make interest and creativity in science more likely, I found every published (and some unpublished studies) that examined the role in personality in scientific interest or scientific creativity from 1950 to 1998. There were 26 studies that reported quantitative effects of personality in scientists compared to non-scientists.

One problem immediately arises when attempting to summarize on the same metric myriad personality findings using different scales and items: How does one standardize the dimensions of personality? Fortunately, the field of personality has recently witnessed a relatively well agreed upon standardization of the basic dimensions of personality and these have been labeled the “Five Factor Model” (FFM) or the “Big Five.” The FFM is based on factor-analytic studies of personality structure that consistently extract five major factors of personality (Costa & McCrae, 1995; Digman, 1990; Goldberg & Rosolack, 1994; John, 1990; McCrae & John, 1992). The five factors have various labels, depending on the specific researcher, but one of the more common labeling systems, and the one adapted here, is the following: Extraversion (E), Agreeableness (A), Conscientiousness (C), Neuroticism (N), and Openness (O) (Costa & McCrae, 1995). For current purposes, I used empirical findings from the literature to classify a trait term or scale onto one of the FFM dimensions (Gerbing & Tuley, 1991; Gough & Bradley, 1995; McCrae, 1991; McCrae & Costa, 1985; McCrae, Costa, & Busch, 1986; McCrae, Costa & Piedmont, 1993; Piedmont, McCrae, & Costa, 1991).

The two strongest effect sizes (medium in magnitude) were for the positive and negative poles of conscientiousness (C; see Table 1). Being high in conscientiousness (C+) consists of scales and items such as careful, cautious, conscientious, fastidious, and self-controlled, whereas being low in conscientiousness (C−)

Table 1
Personality Traits That Increase Interest in. . .

Science
Conscientiousness
Confidence
Dominance
Introversion
Physical science
“Thing” vocational orientation
Asperger’s syndrome
(Extreme) Introversion
Social science
“People” vocational orientation
Psychological mindedness
Extraversion
Subjective-internal theoretical orientation
Empathy
Flexibility
Dominance
Intuitive
Intellectual efficiency

consists only of two scales/items, namely, direct expression of needs and psychopathic deviance. Although the C− dimension comprised only five comparisons, it is clear that relative to non-scientists, scientists are roughly a half a standard deviation higher on conscientiousness and controlling of impulses. In addition, low openness to experience had a median *d* of .30, whereas introversion had a median effect size of .26. Low openness consists of scales such as conventional, rigid, and socialized, whereas introversion consisted of terms such as deferent, reserved, introverted, and dependent. Finally, examining the effect sizes of the two subcomponents of extraversion separately (confidence and sociability), the confidence component had a small positive effect and the sociability component a near zero negative effect. In short, the FFM dimensions of openness, confidence/dominance (E), introversion, and conscientiousness and discipline appear to be the personality factors that make scientific interest most likely.

Personality and interest in social versus physical science. More specific than general interest in science, I also contend that one's preference and orientation toward people or things plays a crucial role in the kind of science that one becomes interested in, especially physical or social science (see Table 1). As discussed already, the foundation for the People-Thing orientation comes from the vocational interest literature. Dale Prediger was the first to modify John Holland's hexagonal model of vocational interests onto two basic dimensions: People-Things and Data-Ideas. The "People" end of the dimension is mapped onto Holland's "Social" career types, whereas the "Thing" end of the dimension is mapped onto "Realistic" career types. According to Holland, the social career type prefers occupations that involve informing, training, enlightening other people. The realistic career type, on the other hand, prefers careers that involve manipulating things, machines, objects, tools, and animals (Holland, 1992; Lippa, 1998; Prediger, 1982).

Supporting this domain-specific view of scientific interest, Simon Baron-Cohen and his colleagues have found that engineers, mathematicians, and physical scientists score much higher on measures of high functioning autism (Asperger's syndrome) than non-scientists, and that physical scientists, mathematicians, and engineers are higher on non-clinical measure of autism than social scientists. In other words, physical scientists often have temperaments that orient them away from the social and toward the inanimate—their interest and ability in science is then just one expression of this orientation. Such an orientation in one sense is an extreme form of introversion, that is, it involves a lack of social interest and a not well-developed sense of theory of mind. Of course, autism and Asperger's syndrome are not simply extreme forms of introversion, but rather their own category of social disorder. Nevertheless, there are important parallels between Asperger's and introversion that warrant them being conceptualized as aspects of a less social personality orientation. Moreover, autistic children are more than twice as likely as non-autistic children to have a father or grandfather who was an engineer (Baron-Cohen et al., 1998, Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Baron-Cohen, Wheelwright, Stone, & Rutherford, 1999; Baron-Cohen, Wheelwright, Stott, Bolton, & Goodyer, 1997).

One problem with the research on personality and scientific interest or achievement is that it is not specific to any specific domain of science, but rather covers scientists in general. Very little if any research has compared the personality dispositions of physical, biological, and social scientists to examine whether the social scientists have more sociable and extraverted personalities compared to their physical scientist peers. Of most interest would be developmental research that examined whether a preference for things is evident early in life for future physical scientists and, likewise, whether a preference for people is evident early in life for future social scientists. Similarly, cross-cultural work showing the same association between thing-orientation and physical science and social-orientation and social science the world over would be quite valuable. Therefore, the next line of research for the personality psychology of science is to explore differences in personality between physical, biological, and social scientists. Based on the evidence just cited, my prediction is that the physical scientists as a group will be more introverted and thing-oriented (that is, have more developed implicit physical intelligence) than the biological scientists, who in turn will be less sociable and extraverted than social scientists (i.e., have more developed implicit social intelligence).

Personality and Theoretical Predilection

In addition to interest in science in general or the physical or social science in particular, there is the question of whether distinct personalities are attracted to different theoretical perspectives in science. As we saw earlier from the meta-analytic review, the answer seems to be yes, certain personality traits do predict interest in science and research, even within the branch of social science of psychology. Clinical psychology, for example, is an ideal domain in which to address this question, because it emphasizes two different and distinct sets of skills in graduate education, namely applied-clinical skills and research and scientific skills. What is known as the "Boulder Model" was implemented in the late 1940s, and it places equal emphasis on training in both research and clinical practice. And yet in reality, a major concern for PhD programs in clinical psychology is the high rate of students who are not interested in science and research. Clinicians do tend to be more people-oriented than investigative and research-oriented (Malinckrodt, Gelso, & Royalty, 1990; Zachar & Leong, 2000).

An important question, therefore, has become, "What predicts interest in science and research in these students and can this interest be increased by particular kinds of training environments?" The general conclusion from the studies on these questions is that one of the strongest predictors in interest in research (or lack thereof) is personality-vocational interest and that training environment plays but a modest role in increasing interest in research (Kahn & Scott, 1997; Mallinckrodt et al., 1990; Royalty & Magoon, 1985; Zachar & Leong 1992, 1997). For example, a study by Mallinckrodt and colleagues (1990) examined the impact of training environment, personality-vocational interest, and the interaction between the two on increasing research interest and found that personality-vocational interest was a stronger predictor than research environment in increasing interest in research over the course of graduate training (see Table 1). I should point out, however, that not everyone agrees with conceptualizing vocational interests and personality together. Waller, Lykken and Tellegen (1995), for instance, argue they are separate dimensions, even if vocational interests can be traits.

In addition, the work on personality can also shed light on theory acceptance and even theory creation. Or stated as a question: Does having a certain personality style predispose a scientist to create, accept, and/or reject certain kinds of theories? The first work on this question was in the mid 1970s by George Atwood and Silvan Tomkins (1976), who showed through case studies how the personality of the theorist influenced his or her theory of personality. More systematic empirical investigations have expanded this work and have demonstrated that personality influences not only theories of personality, but also how quantitatively or qualitatively oriented and how productive psychologists are (Arthur, 2001; Atwood & Tomkins, 1976; Conway, 1988; Costa, McCrae, & Holland, 1984; Hart, 1982; Johnson, Germer, Efran, & Overton, 1988; Simonton, 2000). One general finding from these studies is that psychologists who have more objective and mechanistic theoretical orientations are more rational and extraverted than those who have more subjective and humanistic orientations. For instance, Johnson and colleagues collected personality data on four groups of psychologists (evolutionary-sociobiologists, behaviorists, personality psychologists, and developmental psychologists) and found that distinct personality profiles were evident in the different theoretical groups. That is, scientists who were more holistic, purposive, and constructivist in orientation were higher on the Empathy, Dominance, Intellectual Efficiency, and Flexibility scales of the California Psychological Inventory and the Intuition scale of the Myers-Briggs Type Indicator (MBTI). However, most of these studies have been with psychologists, so answering the question of whether these results generalize to the biological and natural sciences remains a task for future psychologists of science.

Personality and Scientific Achievement and Creativity

Not only do certain traits lower thresholds for scientific interest and theoretical orientation, but a somewhat different pattern of traits also lowers thresholds for scientific creativity and eminence. The meta-analysis conducted by Feist (1998) also addressed the question of which traits make creativity and eminence in science more likely and what their magnitude of effect was. The traits can be arranged into three psychologically meaningful categories: cognitive, motivational, and social.

Cognitive traits that make scientific creativity and eminence more likely. A consistent finding in the personality and creativity in science literature has been that creative and eminent scientists tend to be more open to experience and more flexible in thought than less creative and eminent scientists (see Table 2). Many of these findings stem from data on the flexibility (Fe) and tolerance (To) scales of the California Psychological Inventory (Feist & Barron, 2003; Garwood, 1964; Gough, 1961; Helson, 1971; Helson & Crutchfield, 1970; Parloff & Datta, 1965). The Fe scale, for instance, taps into flexibility and adaptability of thought and behavior as well as the preference for change and novelty (Gough, 1987). The few studies that have reported either no effect or a negative effect of flexibility in scientific creativity have been with student samples (Davids, 1968; Smithers & Batcock, 1970).

For instance, Feist and Barron (2003) examined personality, intellect, potential, and creative achievement in a 44-year longitudinal study. More specifically, they predicted that personality would explain unique variance in creativity over and above that already explained by intellect and potential. Results showed that observer-rated Potential and Intellect at age 27 predicted Lifetime Creativity at age 72, and yet personality variables (such as Tolerance and Psychological Mindedness) explained up to 20% of the variance over and above Potential and Intellect. Specifically, two measures of personality—California Psychological Inventory scales of Tolerance (To) and Psychological Mindedness (Py)–resulted in the 20% increase in variance explained (20%) over and above potential and intellect. The more tolerant and psychologically minded the student was, the more likely he was to make creative achievements over his lifetime. Together, the four predictors (Potential, Intellect, Tolerance, and Psychological Mindedness) explained a little more than a third of the variance in lifetime creative achievement. I should point out that these findings on To and Py mirror very closely those reported by Helson and Pals (2000) in a longitudinal study of women from age 21 to 52.

Table 2
Personality Traits That Make Scientific Creativity More Likely. . .

Cognitive traits
Openness to experience
Tolerance
Flexibility
Social traits
Dominance
Arrogance
Hostility
Introversion
Self-confidence
Motivational traits
Driven
Ambitious
Intrinsically motivated

Motivational traits that make scientific creativity and eminence more likely. The most eminent and creative scientists also tend to be more driven, ambitious, and achievement-oriented than their less eminent peers (see Table 2). Busse and Mansfield (1984), for example, studied the personality characteristics of 196 biologists, 201 chemists, and 171 physicists, and commitment to work (i.e., “need to concentrate intensively over long periods of time on one’s work”) was the strongest predictor of productivity (i.e., publication quantity) even when holding age and professional age constant. Helmreich, Spence, Beane, Lucker, and Matthews (1980) studied a group of 196 academic psychologists and found that different components of achievement and drive had different relationships with objective measures of attainment (i.e., publications and citations). With a self-report measure, they assessed three different aspects of achievement: “mastery” preferring challenging and difficult tasks; “work” enjoying working hard; and “competitiveness” liking interpersonal competition and bettering others. According to Amabile’s (1996) well-known typology, the first two measures could be classified as “intrinsic motives” and the last measure could be an “extrinsic motive.” Helmreich and his colleagues found that mastery and work were positively related to both publication and citation totals, whereas competitiveness was positively related to publications but negatively related to citations. Being intrinsically motivated (mastery and work) appears to increase one’s productivity and positive evaluation by peers (citations), whereas wanting to be superior to peers leads to an increased productivity, and yet a lower positive evaluation by peers. The inference here is that being driven by the need for superiority may backfire in terms of having an impact on the field. Indeed, in a further analysis of the male psychologists in their 1980 data set, Helmreich and colleagues (Helmreich, Spence, & Pred, 1988) factor analyzed the Jenkins Activity Survey and extracted an achievement striving factor and an impatience/irritability factor. Achievement striving was positively related to both citation and publication counts, whereas impatience/irritability was related to neither publications nor citations.

Social traits that make scientific creativity and eminence more likely. In the highly competitive world of science, especially big science, where the most productive and influential continue to be rewarded with more and more of the resources, success is more likely for those who thrive in competitive environments, that is for the dominant, arrogant, hostile and self-confident (see Table 2). For example, Van Zelst and Kerr (1954) collected personality self-descriptions on 514 technical and scientific personnel from a research foundation and a university. Holding age constant, they reported significant partial correlations between productivity and describing oneself as "argumentative," "assertive," and "self-confident." In one of the few studies to examine female scientists, Bachtold and Werner (1972) administered Cattell's 16 Personality Factor to 146 women scientists and found that they were significantly different from women in general on nine of the sixteen scales, including dominance (Factor E) and self-confidence (Factor O). Similarly, Feist (1993) reported a structural equation model of scientific eminence in which the path between observer-rated hostility and eminence was direct and the path between arrogant working style and eminence was indirect but significant (see Figure 2).

The scientific elite also tend to be more aloof, asocial, and introverted than their less creative peers. In a classic study concerning the creative person in science, Roe (1952, 1953) found that creative scientists were more achievement-oriented and less affiliative than less creative scientists. In another seminal study of the scientific personality, Eiduson (1962) found that scientists were independent, curious, sensitive, intelligent, emotionally invested in intellectual work, and relatively happy. Similarly, Chambers (1964) reported that creative psychologists and chemists were markedly more dominant, ambitious, self-sufficient, and had more initiative compared to less creative peers. Helson (1971) compared creative female mathematicians with less creative female mathematicians, matched on IQ. Observers blindly rated the former as having more "unconventional thought processes," as being more "rebellious and nonconforming," and as being less likely to judge "self and others in conventional terms." More recently, Rushton, Murray, and Paunonen (1987) conducted factor analyses of the personality traits most strongly loading on the "research" factor (in contrast to a "teaching" factor) in two separate samples of academic psychologists. Among other results, they found that "independence" tended to load on the research factor, whereas "extraversion" tended to load on the teaching factor.

To summarize the distinguishing traits of creative scientists: they are generally more open and flexible, driven and ambitious, and although they tend to be relatively asocial, when they do interact with others, they tend to be somewhat prone to arrogance, self-confidence, and hostility.

Summary and Conclusions

In this paper, I have summarized and integrated two of the five or six major psychologies of science, namely developmental and personality. Developmental psychology of science has revolved around at least four major topics, three of which I review here: a) familial influences on scientific interest and talent (i.e., birth-order and immigrant status); b) gender and science; and c) age and scientific interest, talent, and productivity. A fourth topic—how children are implicit psychologists, physicists, biologists, and mathematicians—is summarized and reviewed elsewhere (Feist, 2006). Some of the highlights of these findings are:

- Latter-born scientists are more likely to accept novel, revolutionary scientific theories than first-born scientists.
- The scientific elite is about three times more likely to be offspring of foreign-born parents than the population in general.

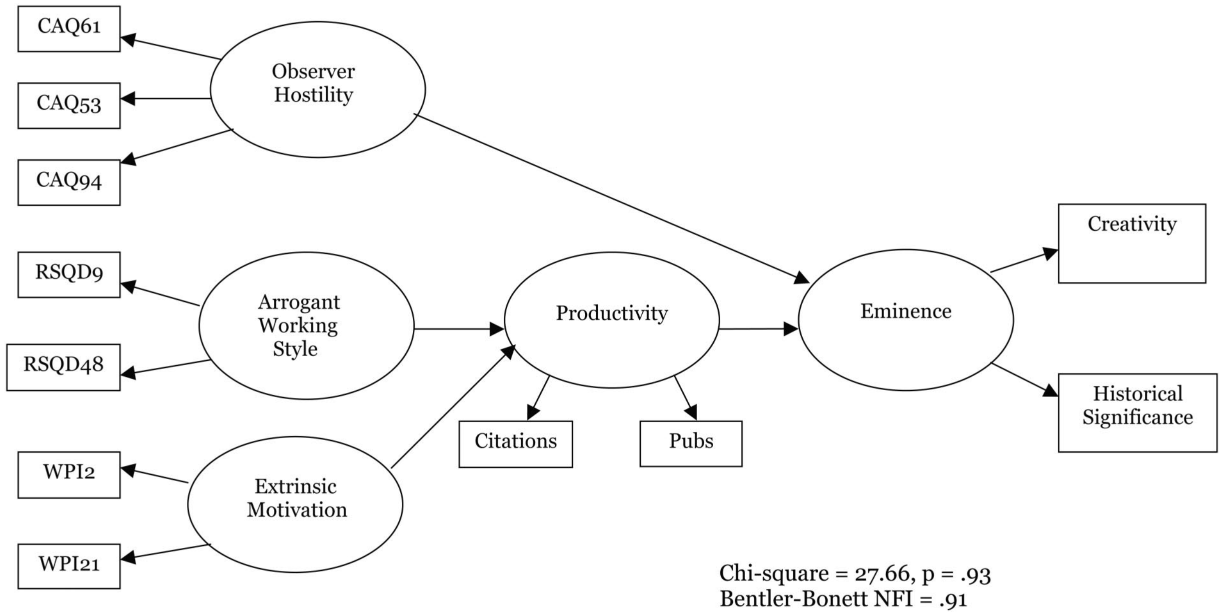

Figure 2. Structural Model of Scientific Eminence. In Feist (1993). Model of scientific eminence. *Psychological Science, 4,* 366-371. Copyright Blackwell Publishing. Reprinted with permission.

- There are some real gender differences in scientific interest and likelihood of remaining in science, but these differences exist mostly in the physical sciences and mostly after adolescence. Causes and explanations for these differences remain unclear and controversial.
- Those who go on to be our scientific elite are very likely to have crystallized their interest in and shown talent for science at an early age (before age 12)
- When plotted against career age, publication rates peak at about 20 years into one's career. The growth rate before this peak is steeper than the decline rate after it.
- Conscientiousness, self-confidence, dominance, and openness are the traits most likely to lower the thresholds for scientific interest.
- Being thing-oriented and introverted lowers one's threshold for interest in and talent for physical science, whereas being people-oriented, psychologically minded, and extraverted do the same for the social science interest and talent.
- Cognitive traits (e.g., tolerance and flexibility), social traits (e.g., dominance, arrogance, hostility), and motivational traits (e.g., driven, intrinsically motivated) each lower thresholds for scientific creativity and achievement.

As the results of this paper should make clear, scientists are people with particular developmental histories and personality traits. Gradually but steadily, what psychologists of science are learning about the nature of scientific interest, motivation, talent, and achievement is reaching a "point of no-return"—that is, if we want to understand what science is at its best and worst, and who does it, then we must include the psychological perspective. No longer can other disciplines that study science ignore the insights into scientific thought and behavior that psychologists are uncovering. More to the point for psychology, no longer can psychologists who study any form of scientific thought or behavior–from the neuroscience of mathematical problem solving to group influence in the scientific laboratory—continue to do so blind to the fact that they are doing "psychology of science."

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