Intelligence xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Intelligence

journal homepage:

Creative performance, expertise acquisition, individual differences, and developmental antecedents: An integrative research agenda

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ARTICLE INFO

Article history:
Received 12 April 2013
Accepted 16 April 2013
Available online xxxx

Keywords:
Creativity
Expertise
Performance
Ability
Disposition

ABSTRACT

This article sketches an integrative research agenda for creative achievement that combines the expertise-acquisition framework with individual differences in cognitive abilities and dispositional traits as well as the genetic and environmental factors underlying the development of those same individual-difference variables. The treatment begins with a discussion of domain-specific creative expertise and performance, a discussion that indicates the added complexities in assessing both variables. The analysis then shifts to substantial individual variation in both expertise acquisition and creative performance, variation that does not sit easily with a simple single-cause conception, particularly when performance appears inversely related to the amount of time taken to attain the requisite expertise. This leads to the question of whether individual-difference variables can account for otherwise inexplicable "faster better" and "more bang for the buck" effects. If so, then the obvious last inquiry concerns the developmental antecedents of those variables, where these antecedents can be both genetic and environmental. The upshot of the suggested analysis should be complex structural equation models that fully accommodate both nature and nurture in explaining exceptional creative performance.
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1. Introduction

Recently I was invited to write a comment for *Nature*, a knock on the door not heard often. I was specifically asked to discuss the place of scientific genius in the modern natural sciences. Having conducted research on the subject for more than three decades, and having followed current trends in the main disciplines of pure research—especially in physics and biology—I responded with a highly speculative "thought piece." The editors did not like it. They wanted something more declarative than inquisitive. Accordingly, the essay went through several revisions, with increasingly more passages inserted by the editors. Even after the *fifth* version was accepted for publication, I received a galley with additional changes, including a rewritten title and summary—all in words not my own. I lodged a protest over the last-minute alterations, but to no avail. Indeed, even after I received the "final" version of the comment during the embargo period, the editors decided to make another dramatic change in the title without seeking my permission: the insertion of "After Einstein" as the main title. The resulting comment has provoked more controversy than anything else associated with my name (Simonton, 2013). I have lost track of the number of times I had to inform irate scientists that I did *not* argue that Albert Einstein was the "last scientific genius."

In retrospect, of course, the *Nature* editors knew exactly what they were doing. They wanted headlines that would draw attention to their journal. That goal was best attained by a provocative, even dogmatic thesis that would create a big splash in the media. The original version of the essay would not have done so: too many qualifications, conjectures, and complications. Indeed, my own historiometric research suggests that taking extremist stances is indeed a virtue. For instance, a study of more than two thousand Western philosophers showed that the most eminent among them were most likely to advocate the most radical and

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http://dx.doi.org/10.1016/j.intell.2013.04.007

Please cite this article as: Simonton, D.K., Creative performance, expertise acquisition, individual differences, and developmental antecedents: An integrative research agenda, *Intelligence* (2013), http://dx.doi.org/10.1016/j.intell.2013.04.007

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uncompromising beliefs (Simonton, 1976). Being a staunch determinist or indeterminist earns more points with posterity than proposing some conciliatory position (viz. compatibilism). The same general effect was found in another study of 54 eminent psychologists (Simonton, 2000b). With respect to the nature–nurture issue, for example, Francis Galton and John B. Watson likely gained considerable fame—or notoriety—for advocating one side or the other rather than the middle. The same long-term benefit even accrues to historic leaders (Simonton, 1984). The recent discovery of King Richard III's skeleton would have caused much less of a stir had he been as morally mediocre as other monarchs of his era. Getting rid of your young nephews may be reprehensible, but such evil acts can also secure you a permanent place not just in history but also in great literature.

Unfortunately, the same extremist advocacy is found in the research on the relation between expertise acquisition and domain-specific performance. In particular, some researchers have attained a high degree of professional and public visibility by taking doctrinaire positions claiming that exceptional achievement can be totally attributed to the amount of "deliberate practice" a person devoted to acquiring the requisite skills and knowledge (e.g., Howe, 1999; cf. Simonton, 2002). Work hard enough and long enough—about a decade minimum—and anybody can become an Albert Einstein. Einstein's former university professor, Hermann Minkowski, might have called his student a "lazy dog" (Hoffmann, 1972, p. 84), and his classmate Marcel Grossmann was clearly the better student by far, but perhaps Einstein was secretly burning the midnight oil when everyone else was fast asleep, enabling him to earn more fame and glory than either his teacher or friend managed to pull off with their seemingly superior expertise.

At great risk to my future impact on the field, I wish to sketch out a research agenda that is integrative rather than polarizing. This sketch will indicate how much we need to know before anyone can even dare to become more forthright in their opinions. The phenomenon of exceptional achievement is much too complicated to permit simplistic, one-sided explanations. In particular, a full understanding requires (a) the identification of all individual-difference variables that correlate with acquisition and performance and (b) the determination of the developmental antecedents, both genetic and environmental, of these identified correlates. In part because my own expertise concentrates on extraordinary creativity, my discussion will focus on examples from that area as well. Just as important, the application of the expertise framework to outstanding creativity is now more than 20 years old (Ericsson, 1999; Hayes, 1989) and has stimulated considerable debate for at least a dozen years (Simonton, 1996, 2000a). That said, the same broad principles should often (even if not always) apply to many other domains of human achievement, such as sports, chess, musical performance, and even various forms of leadership. The main differences in the applications mostly involve the complexity of the phenomena. Roughly put, exceptional leadership is probably the most complex, followed by creativity, and then musical performance, chess, and sports.

2. Domain-specific expertise and creative performance

The first item on the agenda is the most basic but perhaps also the most difficult, namely, the answer to two questions: First, what does it mean to have expertise in a creative domain? Second, what does it mean to exhibit exceptional performance in a creative domain?

2.1. What is creative expertise?

Starting with the first question, too often advocates of "expertise acquisition is all you need" assume from the very start the existence of some precisely defined domain that can be mastered through sufficient training and practice. This assumption often makes perfect sense because those proponents tend to focus on well-established domains that have been around for decades if not centuries and that have not changed anything fundamental about the nature of the domain (Ericsson, 1996; Ericsson, Charness, Feltovich, & Hoffman, 2006). For example, the original research on expertise came from work on expertise in chess (e.g., Simon & Chase, 1973). Yet chess is a game that has a very long history and that has not changed any essential principles for centuries. Chess expertise is also so well established that computers have been programmed to play the game at the highest levels of performance, even beating the world chess champion (Hsu, 2002). It is conceivable that the situation might change when the domain-specific expertise is not so precisely defined. Consider the following two points:

First, sometimes the expertise does not exist until it is first created. An example is Galileo's creation of telescopic astronomy (Simonton, 2012a). After using trial-and-error to devise a new instrument suitable for observing the night sky, he carried out a series of observations that revolutionized astronomy, including the mountains on the moon, the moons of Jupiter, the stars of the Milky Way, the phases of Venus, the spots on the sun, and the striking abnormality in Saturn's image that was later resolved into its rings. Yet these discoveries had no basis in any existing scientific expertise. On the contrary, almost everything he observed conflicted with both Ptolemaic astronomy and Aristotelian cosmology, and his newfangled telescope had no justification in contemporary optics (a problem only later worked out by Kepler). As a result, many if not most "experts" of his day at first rejected his claims as mere optical illusions. Interestingly, the expertise that actually proved most useful to his observations was his prior training in the visual arts, such as chiaroscuro drawing, that enabled him to interpret correctly what other observers had completely missed, even after the discoveries were initially announced. Even so, nobody at the time could have anticipated that such artistic background would have proved useful. An analogous narrative is witnessed in Antonie van Leeuwenhoek's observations in microscopic biology, achievements that were based not on optics or biology but rather on the high-quality textile trade (Simonton, 2012a). Leeuwenhoek's discoveries were likewise rejected by the scientific "experts" who could not figure out how a simple tradesman, with no scientific education, made a one-lens microscope that multiplied objects hundreds of times, revealing spermazoa, protozoa, bacteria, blood cells, and other basic life forms never known before.

Second, even when a domain-specific expertise is pretty much defined in advance, that expertise can be conceived multiple ways, making it difficult to determine precisely what optimal subset of that generalized expertise is most relevant to a particular performance criterion. A concrete example is the composition of an opera in the classical

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repertoire. Such a creative product involves the ability to write music for both orchestra and voice—including solo, duet, and chorus—and often to do so in more than one form, including ballet. Making matters even more complicated, operas feature multiple genres so that composing a comic opera requires a different expertise than composing a dramatic opera. Now one might expect that the best choice for an opera composer would be to specialize not just on opera, but also on a particular genre of opera. That career choice would optimize the most relevant expertise. Yet the contrary is the case (Simonton, 2000a). The most successful opera composers also are prone to create non-operatic compositions and even their operatic compositions tend to represent a mix of genres. In a sense, the composers avoid "overtraining" by engaging in "cross-training." It would be comparable to chess masters trying to improve their game by practicing checkers and Go.

The same pattern is observed in scientific creativity (Simonton, 2004). Rather than pursue a single research question representing a specialized area of expertise, the most creative scientists tend to engage in "networks of enterprise" in which they pursue a large number of loosely related projects (Gruber, 1989). Better yet, highly creative scientists also tend to have creative hobbies and interests well outside of any scientific domain (Root-Bernstein, Bernstein, & Garnier, 1995; Root-Bernstein et al., 2008). Galileo's fascination with art, literature, and music offers a prime example (Simonton, 2012a). Thus, the most creative acquire a breath of interests that enables them to "think outside the box" defined by any existing domain-specific expertise.

2.2. What is creative performance?

Again, many of the domains that initially inspired the expertise-acquisition framework featured well-defined goals and explicit means to attain those goals. Another example besides chess is instrumental performance in the classical repertoire (Ericsson, Krampe, & Tesch-Römer, 1993; Howe, Davidson, & Sloboda, 1998). Many of the domains on which the research has focused also rely heavily on exactly replicable behaviors, a characteristic not only of instrumental performance but also of almost all sports (Ericsson, 1996). Yet not all domains of exceptional achievement fit these expectations. In creative domains, specifically, the goals and means may be constantly changing, and behavioral replication is antithetical to success. For instance, once Einstein published his first paper on special relativity, he certainly no longer had the option of publishing the same paper again. Furthermore, once that paper was published, it changed the body of knowledge so that later papers would have to be written with that first paper as context. In Einstein's case, the first relativity paper allowed him to write a second (and much shorter) paper introducing the famous eq. $E = mc^2$. This essential difference is not restricted to Einstein's experience. On the contrary, the contrast is inherent in the very definition of what counts as a creative idea. Such an idea must satisfy three quantitative criteria (Simonton, 2012b).

First, the idea must be highly *original* in the sense of a low probability of initial generation. Repeating an idea obviously violates this criterion. If Beethoven or anybody else had written a second Fifth Symphony exactly like the first, that person would accrue absolutely no credit for originality. In contrast, if an NBA basketball player makes one free throw after another with a perfect swish each time, he provokes admiration rather than disdain.

Second, the idea must be *useful* in the broad sense of satisfying some utility standards, whether scientific or esthetic. Yet as suggested in the earlier Einstein example, these standards change as the direct result of past acts of creativity. In the arts, for example, creators are usually under constant pressure to surpass what they have done before, a pressure that drives them toward ever increasing originality (Martindale, 1990). Hence, what was effective in a previous creative product frequently becomes ineffective in another—the new artistic trick loses its "shock value." This shift in assessment would be comparable to telling a star tennis player with an unreturnable serve that she cannot be scored with another ace unless the next serve delivers the ball at an even faster velocity than the first serve. In creativity, the bar is always being raised by previous acts of creativity.

Third, the idea must be *surprising*. This last criterion corresponds to the "nonobvious" standard used by the United States Patent Office to evaluate applications for patent protection (http://www.uspto.gov/inventors/patents.jsp; see also Sawyer, 2008). Significantly, this patent criterion is based on a person who has "ordinary skill in the art," that is, someone who has the relevant expertise (http://www.uspto.gov/web/offices/pac/mpep/documents/2100_2141_03.htm). Ideas that could have been generated by anyone with the same domain-specific knowledge and skill are considered obvious and hence unpatentable. This third criterion is applicable to other forms of creativity, including discovery. The discoveries of Galileo and Leeuwenhoek were certainly surprising to everybody, expert and novice alike (Simonton, 2012a).

Taken together, the three criteria of creativity raise serious doubts about whether exceptional creative performance can be easily and exhaustively subsumed under an expertise-acquisition framework (Simonton, 2012b). To the extent that domain-specific expertise directly generates an idea, the idea cannot be creative. For this reason, to a certain extent creative ideas must be generated "blind" (Simonton, in press-a). This necessity provides the core rationale for the blind-variation and selective-retention theory of creative thought (BVSR; Campbell, 1960; Simonton, 2011). BVSR is called into play whenever expertise proves insufficient.

3. Variation and correlation in acquisition and creative performance

I earlier alluded to what has come to be known as the "10-year rule" (Ericsson, 1996). Supposedly, a person needs a full decade of intensive study and practice before attaining world-class expertise in a given domain of achievement. The facts are far more complex. The "rule" is not a rule and the "10" is nothing more than a convenient round number. One of the most fundamental principles in psychology is that on any attribute people vary substantially around some central tendency. Although this variation is often expressed with respect to the normal distribution or "bell curve," it need not be, and often the distribution will be highly skewed, with a long upper tail. As an example, one study of 120 classical composers found that, on the average, nearly a decade of compositional practice lapsed before the first major works

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appeared (Simonton, 1991b). Nonetheless, the standard deviation was almost as large, and the range exceeded three decades, with many composers taking less than 10 years and even more requiring more than that interval (cf. Hayes, 1989). Some relatively rare composers just "get better faster" (see also Simonton, in press-b).

It is not just the expertise-acquisition period that exhibits substantial cross-sectional variation: expert performance does as well (Simonton, 1997). Often the expertise researchers will rest satisfied with rough categories, such as the expert versus novice distinction (Ericsson et al., 1993). Yet even so-called experts in creative domains contrast greatly in the magnitude of their achievement (Murray, 2003). The 120 composers who made up the study mentioned earlier formed a very elite group given that the number of eligible composers runs into the hundreds if not thousands (Simonton, 1991b). Even so, the sample included a composer like Josef Suk, who really cannot be mentioned in the same breath as Bach, Mozart, or Beethoven. Indeed, Suk was fortunate even to make it into the sample (cf. Farnsworth, 1969; Murray, 2003). After all, his inclusion was based on a single work (Barlow & Morgenstern, 1948). Such "one-hit wonders" are actually common in classical music (Kozbelt, 2008). These creators clearly satisfied the threshold level for compositional mastery, yet never went on to demonstrate the prolific output of masterworks characteristic of the highest levels of creative performance (Simonton, 1997). Bach, Mozart, and Beethoven alone are responsible for nearly a fifth of the compositions making up the standard repertoire in classical music (Moles, 1958/1968). Hence, the creative performance of that triad is several orders of magnitude greater than the far more numerous also-rans who managed to have created one work that is only occasionally performed—frequently as an encore piece by a virtuoso instrumentalist or vocalist who happens to be its rare champion.

I have thus established that even creative "experts" vary greatly (a) in speed of expertise acquisition and (b) in the magnitude of their performance based on that acquired expertise. Given these two variables, the obvious question is their correlation. Are the two variables correlated positively, negatively, or not at all? Surprisingly, this issue is seldom addressed. Too often, it is deemed sufficient to show that experts have engaged in more deliberate practice than did novices, ignoring the fact that not all experts attain the same levels of performance. Nevertheless, what little empirical evidence is available suggests that experts who perform at the highest levels tended to take less time than average in acquiring the necessary expertise (e.g., Simonton, 1991a,b, 1992b; see also Wai, Lubinski, & Benbow, 2005). Such individuals not only got better faster, but also seem to "get more bang for the buck," accomplishing much more with a given amount of expertise (Simonton, in press-b). This inverse relation implies that something is very seriously missing from the basic expertise-acquisition framework. What might have been overlooked? That constitutes the next item on the proposed research agenda.

4. Individual-difference correlates

Persons differ in much more than speed of expertise acquisition and magnitude of performance: They also vary in a large number of other individual-difference variables. These variables fall into two broad categories. The first category includes all cognitive abilities, including both general intelligence and the various special factors, such as verbal, spatial, and mathematical, and their numerous component abilities, such as vocabulary, mental rotation, and arithmetic. The second category encompasses all dispositional traits, whether personality, interests, or values. Given that all of these variables can boast of highly reliable and validated assessment instruments, the next question is whether individual differences on these abilities and traits correlate with either acquisition or performance in creative domains. Although certainly more research needs to be conducted on this question, sufficient evidence has already accumulated to support an affirmative answer (e.g., Cattell & Butcher, 1968; Chambers, 1964; Eysenck, 1997; Feist, 1998; Kuncel, Hezlett, & Ones, 2004). To be sure, each domain of achievement will feature a distinctive profile of abilities and traits that will optimize either acquisition or performance or both (Simonton, 1999, 2008, 2009), yet the existence of such correlates cannot be denied by any scientist willing to look at the empirical evidence with an unbiased eye (Simonton, in press-b). Non-trivial effect sizes cannot be just swept under the rug.

Therefore, a critical agenda item for future research is to articulate precisely how these diverse individual-differences contribute to both acquisition and performance. To what extent do certain abilities or traits allow an individual to accelerate expertise acquisition? To what degree do specific ability and trait variables permit a person to attain higher levels of performance for a given amount of acquired expertise? Moreover, exactly how are these influences carried out? For example, what roles do specific interests or values play in maintaining a regimen of practice or study? How do exceptional special abilities enhance performance even after controlling for level of expertise attained? Finally, are the individual-difference variables the same for acquisition and performance or are different ability or trait profiles required? For instance, in terms of the Big Five Factor model (Feist, 1998), might not conscientiousness be more important for expertise acquisition but openness to experience more crucial for creative performance?

A proponent of the pure expertise-acquisition position might criticize the foregoing questions as relying too heavily on correlational rather than experimental methods for the empirical answers. The cause–effect relation cannot then be easily teased out. To illustrate, it may very well be that conscientiousness correlates with the rate of expertise acquisition, but the latter variable is responsible for the former variable: The arduous daily task of deliberate practice helps a person develop the necessary self-discipline. My response to this objection is twofold. First, the evidence for deliberate practice is also almost entirely correlational rather than experimental. Beyond doubt, no investigation to date randomly assigned a heterogeneous sample of participants to two groups, one forced to engage in a decade in deliberate practice and another obliged to do quite otherwise. Quite the reverse: Every participant self-selected the "treatment," deciding whether to engage in the hypothesized requirement. Second, the individual-difference variables will most often feature antecedents that enable the researcher to establish some causal priority to the analysis of the correlational data. This second point needs its own section for elaboration.

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5. Genetic and environmental antecedents

I just suggested that the correlates of expertise acquisition and expert performance in creative domains might very well have their own antecedents, antecedents that must be considered exogenous to either acquisition or performance. If these underlying sources of individual differences can be identified, then it aids the argument that the individual-difference variables actively facilitate both "better faster" and "more bang for the buck" effects. These hypothesized prior variables fall naturally into two main categories: genetic and environmental.

Of course, the genetic basis for exceptional accomplishment harks back to Galton's (1869) *Hereditary Genius*, where "genius" was taken to encompass not just extraordinary creativity and leadership but also scholastic and athletic achievement. Although Galton took an extremist position on the nature–nurture issue, modern behavioral genetics has determined beyond any scientific doubt that many if not most important individual-difference variables feature substantial heritability coefficients (e.g., Bouchard, 2004; Bouchard, Lykken, McGue, Segal, & Tellegen, 1990). These coefficients are found for both cognitive abilities and dispositional traits. Just as significant, these genetically influenced variables include predictors of both acquisition and performance in creative domains (Simonton, 2008).[1] By combining the latter correlations with the corresponding heritabilities for the same variables, we can estimate that somewhere between a quarter and a third of the variance in acquisition or performance can be attributed to genetic factors (Simonton, 2008; see also Bouchard & Lykken, 1999).

Curiously, the environmental basis for exceptional achievement also dates back to Galton, only this time to his 1874 *English Men of Science: Their Nature and Nurture*. As the book's subtitle suggests, Galton retreated somewhat from his unadulterated genetic determinism: He attempted to identify childhood and adolescent experiences in both family and school that might also contribute to development, in this case concentrating on scientific creativity. One particular experience is of special interest here because it is inherently an exogenous variable, namely, birth order. Galton showed that highly eminent scientists were more likely to be first-born sons, thus initiating a long series of inquiries into the developmental effects of birth order on both achievement and individual-differences, where the latter can include both cognitive abilities and personality traits that correlate with creative achievement (e.g., Paulhus, Trapnell, & Chen, 1999; Sulloway, 2007).

I picked birth order only because of its obvious independence from genetic factors. Other environmental experiences are also likely to prove influential, but it is not always easy to separate them out from the genetic contributions (Scarr & McCartney, 1983). A classic example is a person's socioeconomic origins, which conflates the impacts of parental phenotypes and genotypes. Nevertheless, if the sample of creative individuals is heterogeneous with respect to time and place of birth, the investigator can include various indicators of sociocultural, political, and economic context that have been shown to affect creativity in both development and manifestation (Simonton, 2003). These environmental influences would very likely be largely orthogonal to genetic factors. An instance is role-model availability, that is, exposure in childhood and adolescence to highly eminent figures in the particular domain (Simonton, 1975, 1988, 1992a; Walberg, Rasher, & Parkerson, 1980).

I have avoided introducing such potential complications as genetic–environmental interaction effects and non-additive inheritance such as emergenesis (cf. Simonton, 1999; Waller, Bouchard, Lykken, Tellegen, & Blacker, 1993). Yet even within this simplified agenda, the main point remains: A complete treatment of the individual-difference correlates of expertise acquisition and performance requires an investigation into the underlying developmental antecedents.

6. Consolidation

The agenda outlined in the preceding sections can be consolidated by suggesting that creativity researchers begin with a corresponding set of basic recursive structural equation models (cf. Feist, 1993; Rodgers & Maranto, 1989; Simonton, 1977). The schematic features of this suggested research agenda are represented in Fig. 1.

This figure must not be interpreted as a simple path diagram with latent variables. Because each circle actually includes a whole set of variables, the arrows also encompass multiple potential effects from one cluster to another. In other words, the diagram is intended to represent a whole class of structural models that contain all direct and indirect effects on either acquisition or performance. The variable clusters themselves are defined as follows:

CP creative performance criteria, such as productivity, impact, peer recognition, major awards, and historiometric eminence, (e.g., Albert, 1975; Carson, Peterson, & Higgins, 2005; Feist, 1993; Simonton, 1997). The specific criteria will depend on the domain of creativity (e.g., citation rates are less relevant in the arts). If the criteria within a given creative domain all highly correlate, they can be collected together as indicators of an underlying latent variable assessing creative achievement (cf. Simonton, 1991c).

DP deliberate practice variables that impact on one or more variables in set *CP*, such as directed reading, formal writing, problem sets, skill exercises, including laboratory work or artistic rehearsals, and perhaps even implicit drills, such as going through peer review (cf. Chambers, 1964; Hayes, 1989; Simonton, 1991b). Again, the specific practice behaviors will vary according to the domain of creativity (e.g., art versus science).

CA cognitive abilities, both general and specific, that have direct effects on variables contained in *CP*, *DP*,

[1] One anonymous referee wondered why "there is so little genetic research on acquisition." In truth, behavioral geneticists who have examined the basic cognitive processes involved in acquisition, such as speed of information processing, have found prominent genetic loadings (Bouchard et al., 1990). However, these estimates depend on twin studies. To apply the same methods to the acquisition of domain-specific expertise would require large samples of twins who attempted to master the same expertise. That requirement cannot be realized. Even so, researchers are now acquiring the capacity to identify DNA markers on the human genome that will eventually permit direct assessments on the broader population (e.g., Plomin et al., 2013).

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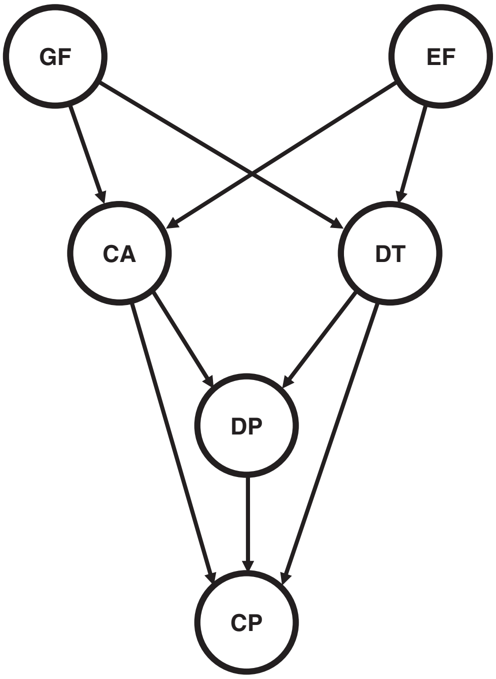

Fig. 1. Suggested research agenda for investigating individual differences in creative performance (*CP*) as a direct function of corresponding differences in deliberate practice (*DP*), cognitive abilities (*CA*), and dispositional traits (*DT*), and as an indirect function of genetic factors (*GF*) and environmental factors (*EF*), with *DP*, *CA*, and *DT* providing the mediating variables. Here *GF*, *EF*, *CA*, *DT*, *DP*, and *CP* each indicate *sets* of variables rather than single variables, where *CA* and *DT* contain phenotypic variables and *GF* genotypic variables. Correspondingly, the arrows connecting the sets indicate multiple potential direct effects from variables in one set to variables in the other set. The variables themselves may be either observed or latent (as holds in set *GF*).

or both (see, e.g., Kuncel et al., 2004; Park, Lubinski, & Benbow, 2007; Roe, 1953). General intelligence and spatial ability are examples. To ensure that these variables are truly antecedent to those in *CP* and *DP*, they should be either highly stable across time or else assessed prior to the onset of deliberate practice and creative performance. The same provisions hold for the next set.

DT dispositional traits, including personality, interests, and values, that have direct effects on variables contained in *CP*, *DP*, or both (e.g., openness to experience; Carson et al., 2005; Harris, 2004; King, Walker, & Broyles, 1996). These dispositional predictors must be added because they usually account for variance in creativity that is not accounted for by abilities alone (e.g., Feist & Barron, 2003). Indeed, often disposition, and especially motivation, can prove far more important than cognitive ability (Cox, 1926; Duckworth, Peterson, Matthews, & Kelly, 2007; Roe, 1953).

GF factors that provide a partial genetic basis for the variables in sets *CA* and *DT* (i.e., those cognitive abilities and dispositional traits having substantial heritability coefficients; e.g., Bouchard et al., 1990; Loehlin, McCrae, Costa, & John, 1998). Under appropriate conditions, the square roots of the variable heredities provide first-pass estimates of the structural parameters for the direct effects on the variables in *CA* and *DT* (Ilies, Gerhardt, & Le, 2004; Simonton, 2008).

EF environmental factors that also provide a partial basis for the variables in sets *CA* and *DT* (including both shared and nonshared effects; e.g., Raskin, 1936; Schaefer & Anastasi, 1968; Simonton, 1987; Walberg et al., 1980). It is assumed that all variables in *EF* are orthogonal to all variables in *GF*. If that is not true, then the shared variance must be removed to obtain pure estimates of "nature" and "nurture." Furthermore, these variables must also be temporally prior to the individual-difference variables in *CA* and *DT*.

To keep the consolidation manageable, this additive and linear recursive model ignored any (a) two-way causal effects, (b) curvilinear effects, (c) multiplicative effects, and (d) causal chains involving more than three direct effects. These niceties can be incorporated if future empirical research indicates that such complications must be added to the overall model.

Using this basic system, we can then define what it means to have a "talent" for creativity in a particular domain, where talent is taken to reflect genetic influences (as treated in Simonton, 2008). Because there are no arrows going directly from *GF* to either *DP* or *CP*, talent is not hypothesized to determine deliberate practice or creative performance directly, so the influences must be indirect. To be specific, genetically-based talent plays a role in creative performance to the extent that there exist individual-difference variables contained in *CA* and *DT* that have a genetic basis among the variables in *GF*, that is, the direct causes of *DP* or *CP* have non-zero heritability coefficients. Given the very large number of individual-difference variables that feature substantial heritabilities, then the only realistic route to denying the impact of talent as here defined is to remove arrows lower down in the graph (i.e., those more endogenous). In particular, the impact of genetically-based talent is absolutely ruled out if *both* of the following conditions hold.

Condition 1 Individual differences in deliberate practice must be totally uninfluenced by individual differences in any cognitive ability or dispositional trait that has non-zero heritability. The complete absence of any such causal effects would necessarily rule out any talent-based "better faster" effects, which represent a special case.

Condition 2 Individual differences in creative performance must be totally uninfluenced by individual differences in any cognitive ability or dispositional trait having non-zero heritability. The utter lack of any such causal effects would have to disprove any talent-based "more bang for the buck" effects, which again form a specific example.

If both of the above stipulations are confirmed, then the hypothesized genetic influences contained in *GF* have no relevance for understanding exceptional creativity. The only question that would remain is whether any potential individual-difference variables in *EF* impinge on the direct causes of either *DP* or *CP*, in which case we can identify the environmental antecedents of creative performance. Those

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EF variables would then represent "nurture" effects in creative development mediated by either abilities or traits. However, if one or both of these two conditions are empirically disconfirmed, then it is logically permissible to speak of someone having some degree of "talent" or "natural" capacity for creativity in a particular domain. Whenever that inference holds, then the next step is to gauge the extent of the indirect genetic effect on deliberate practice, creative performance, or both (Simonton, 2008; cf. Ilies et al., 2004). In effect, this determination requires an examination of the reduced-form equations that specify *DP* or *CP* variables as a function of variables in *GF* and *EF*.

Naturally, this far more nuanced reality may not grab headlines or citations like the simplistic 10-year rule, which concentrates the spotlight on solely the collective arrow from *DP* to *CP*, leaving all else in darkness. Nonetheless, such findings might just get us closer to genuinely scientific knowledge.[2] That prospect makes the future much brighter.

[2] Needless to say, until we can generally identify DNA markers for all relevant abilities and traits (see Footnote 1), it is highly doubtful that the full structural equation model schematically represented in Fig. 1 can be tested all at once in a single sample. The model would more likely have to be built up piecemeal, different inquiries concentrating on various portions, especially the top half versus the bottom half. Meta-analytic procedures would then be used to integrate the various results into a single model (see, e.g., Ilies et al., 2004; Schmidt, 1992). Special care must be taken to recalibrate heritabilities calculated from twin samples for the samples used to determine the predictors of acquisition and performance. The task would not be easy, but the phenomenon of exceptional creativity is far too complex to permit simple science.

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Please cite this article as: Simonton, D.K., Creative performance, expertise acquisition, individual differences, and developmental antecedents: An integrative research agenda, *Intelligence* (2013), http://dx.doi.org/10.1016/j.intell.2013.04.007

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Please cite this article as: Simonton, D.K., Creative performance, expertise acquisition, individual differences, and developmental antecedents: An integrative research agenda, *Intelligence* (2013), http://dx.doi.org/10.1016/j.intell.2013.04.007