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A Behavioral Genetic Perspective on Noncognitive Factors and Academic Achievement

Elliot M. Tucker-Drob

&

K. Paige Harden

Department of Psychology and Population Research Center

University of Texas at Austin

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Address Correspondences to: Elliot M. Tucker-Drob, Department of Psychology, University of Texas at Austin, 108 E. Dean Keeton Stop A8000, Austin, TX 78712-1043. Email: tuckerdrob@utexas.edu. Phone: 512-471-1406.

A Behavioral Genetic Perspective on Noncognitive Factors and Academic Achievement

Interest in “noncognitive” factors (also called “soft” skills) has surged in recent years. As suggested by their name, noncognitive factors are typically defined by what they are not – they are not measures of intelligence or cognitive ability (“hard skills”, which are most typically measured using performance-based psychometric tests). Implicit in the use of the term noncognitive *skills* is also the assumption that they are useful for, or at least statistically predictive of, success and accomplishment in educational settings, and in life more generally. Although theorists have differed regarding which constructs fall under the rubric of noncognitive skills (Farrington et al., 2012), these skills can be generally defined as systematic patterns of thinking, feeling, and behaving that are relevant for academic success and accomplishment. Noncognitive factors therefore include intellectual interest, achievement motivation, conscientiousness, grit, academic self-concept, and attitudes toward education. In this paper, we describe a transactional framework for understanding how individual differences in noncognitive skills relate to cognitive development and academic achievement. Within this framework, research from social and educational psychology on noncognitive skills can be integrated with research from behavior genetics on cognitive development and academic achievement. Considering these rather disparate lines of inquiry together points to future directions for understanding children’s development.

Transactional Models of Gene-Environment Correlation

Historically, genetic influences on cognitive development and academic achievement were conceptualized as competing with environmental influences. Large genetic effects on cognition and achievement were thought to leave little room for environmental influence. Contemporary developmental behavioral genetic thinking sharply contrasts with this perspective. Rather than competing with environmental influences, genetic influences on cognitive development and academic achievement are thought to depend on reciprocal transactions between an individual’s genetically-influenced traits and inputs from his or her environment.

A central component of this transactional process is what is known as *gene-environment correlation*, or *r*GE. Gene-environment correlation refers simply to the fact that people with certain genotypes are systematically (i.e., nonrandomly) more or less likely to experience certain environmental experiences. Gene-environment correlations can arise via three general mechanisms, which were proposed by Plomin, DeFries, and Loehlin (1977) and by Scarr and McCartney (1983). *Passive* gene-environment correlations arise when children are raised by their biological parents, and thus inherit genes from the same people who are also providing their rearing environments. For example, adults who are in more cognitively skilled jobs (e.g., lawyer) tend to make more money than adults in less cognitively demanding jobs (e.g., waiter). Consequently, children who inherit genes for higher cognitive ability from their parents are also more likely to grow up in socioeconomically advantaged homes. Passive gene-environment correlation can thus represent a "double whammy," in that children who are at genetic risk for educational difficulties are also more likely to be raised in family environments that confer additional risk for educational difficulties.

Active gene-environment correlations arise when children actively seek out different environmental experiences on the basis of their interests, preferences, proclivities, and aptitudes – which are, in part, influenced by genes. For example, an adolescent who likes to read is more likely than one who doesn't to enroll in a demanding literature course at school. In this way, two children who are ostensibly provided with equivalent learning opportunities (e.g. attending the same school) will differ in how actively they take advantage of those opportunities (e.g. enrolling in additional, or more challenging, courses).

Evocative gene-environment correlations arise when children evoke different environmental experiences from others in their surroundings on the basis of observable patterns of behaving – which, again, are at least partially genetically influenced. For example, bright, motivated children are more likely to be placed in advanced classes (e.g., gifted and talented programs) and to receive praise from teachers, whereas children with behavioral problems are more likely to be placed in remedial classes and to be removed from the classroom for punishments (e.g., suspensions).

Finally, a fourth form of gene-environment correlation – only briefly considered by Plomin et al. (1977) – arises when children exposed to the exact same environmental experience differentially attend to or interpret that environment. For instance, children attending the same classroom lecture may differ in the extent to which they attend to and engage in the lecture versus daydream, pass notes, or doodle in their notebook.[1] We suggest the term *attentional* gene-environment correlation to refer to this process.

Transactional models of cognitive development build on the concept of gene-environment correlation: Not only are individuals with particular genotypes posited to select, evoke, and attend to particular environments, but these environments are posited to have causal, reciprocal influences on cognitive abilities and academic achievement (Tucker-Drob, Briley, & Harden, 2013). Transactional models can therefore be contrasted with perspectives that conceptualize gene-environment correlations simply as a source of confounding, in which largely impotent environmental experiences become associated with genetic differences, such that environments are inappropriately credited as causal for cognitive development and academic achievement in non-genetic designs (cf. Johnson, Turkheimer, Gottesman, & Bouchard, 2009). Rather, genotype-environment correlation is predicted to lead to differences in potent environmental experiences that promote (or possibly interfere with) cognitive development and academic achievement. According to transactional models, because the experiences relevant to cognition and achievement are nonrandomly experienced as a function of genotype, the effect of environmental influence is to amplify heritable variation in achievement (Briley & Tucker-Drob, 2013; Tucker-Drob et al., 2013). In summary, although genetically informative research has conventionally sought to distinguish selection from causation, transactional models postulate that selection and causation work together in a dynamical system to affect psychological development.

Noncognitive Factors as Driving Forces in Academically-Relevant Gene-Environment Transactions

What are the specific genetically-influenced factors that lead children to differentially select, evoke, and attend to cognitively stimulating learning experiences? Dickens and Flynn (2001) proposed that earlier levels of cognitive ability are the driving forces of gene-environment correlation for intelligence. Specifically, they reasoned that early, relatively weak, genetic influences on cognitive ability

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[1] In briefly considering this form of *r*GE, Plomin et al. (1977) gave the example of "the optimist selecting an environment suited to his genotype when he looks at his world through his rose-colored glasses."

become amplified through a cascading process in which “higher IQ leads one into better environments causing still higher IQ, and so on.” More recently, we have proposed that “noncognitive factors – including levels of scholastic motivation, drive for achievement, intellectual self-concept, and intellectual interest – are also critical for the process of selecting environmental niches” (Tucker-Drob & Harden, 2012a), and that “children select, evoke, and attend to learning experiences that are consistent with genetically influenced individual differences in their motivation to learn” (Tucker-Drob & Harden, 2012b).

Our proposal, illustrated in Figure 1, builds on several pre-existing theories. Cattell originally proposed *investment theory* in the context of his broader theory of fluid and crystallized intelligence. Cattell hypothesized that that “this year’s crystallized ability level is a function of last year’s fluid ability level – and last year’s interest in school work and abstract problems generally” (Cattell, 1987, p. 139 [original publication 1971]). To elaborate, Cattell proposed that knowledge acquisition results from effortfully reasoning through cognitively challenging problems and ideas. Upon success, the procedural and the declarative knowledge gleaned “crystallizes.” According to the investment hypothesis, therefore, learning is thought to depend both on noncognitive factors that lead children to engage effortfully with challenging problems, and on cognitive factors that enable children to determine efficient procedures and mental schemas for solving and understanding those problems. Investment theory, which resembles Piaget’s theory of *accommodation*, has been elaborated on by several authors, including Ackerman (1996) and Chamorro-Premuzic and Furnham (2004).

Although investment theory highlights the dual roles of both cognitive ability and noncognitive factors, it does not specifically link noncognitive factors to genetic differences. In contrast, Hayes’ (1962) *Experience Producing Drive theory* appears to have been one of the first to suggest that genetic influences on intelligence might be mediated by noncognitive factors. Hayes wrote that, “Intelligence is acquired by learning, and inherited motivational makeup influences the kind and amount of learning which occurs. The hereditary basis of intelligence consists of drives, rather than abilities as such” (p. 302). Experiencing

Figure 1. A conceptual model for the mutual relations between interests, proximal environments, and achievement. Reproduced from Tucker-Drob and Harden (2012a).

Producing Drive theory has been elaborated on by Bouchard (1997) and, more recently, by Johnson (2010). Johnson (2010), for example, wrote:

> "genes exert their influences on the development of …traits through their control of motivations, preferences, and emotional responses. Over time, these motivations, preferences, and emotional responses drive the acquisition of experiences that result in the development, practice, and pursuance of skills, habits, patterns of response, and environmental circumstances, which in turn reinforce the underlying drivers."

In arguing for the importance of noncognitive factors, Hayes (1962) wrote that "use of the plural, 'experience-producing drives' (EPD), raises the question of how many such mechanisms are involved." Indeed, many different academically-relevant noncognitive factors have been mentioned in the literature, and many different instruments have been developed to measure them. For example, Heckman and Ruinstein (2001) have written that, "motivation, tenacity, trustworthiness, and perseverance are important traits for success in life." Similarly, Duckworth and Yeager (in press) have written, "There has been perennial interest in personal qualities other than cognitive ability that determine success, including self-control, grit, growth mindset, and many others." In the following section, we describe some of the key noncognitive factors that have been investigated in the social, developmental, and educational psychology literatures. We evaluate whether there is evidence to support the hypothesis that each noncognitive factor is involved in gene-environment transactions in the development of academic achievement.

Criteria for the Role of Noncognitive Factors in Gene-Environment Transactions

Before surveying the specific noncognitive factors that have been routinely mentioned in the psychological literature, it is useful to consider what sorts of empirical evidence would be necessary to support the hypothesis that a noncognitive factor is involved in academically-relevant gene-environment transactions. We propose six general criteria:

Criterion 1. First, the noncognitive factor should be correlated with academic achievement. In the absence of suppression effects (caused, for example, by a compensatory process), a correlation is a necessary (though not sufficient) condition of causality within the naturally occurring system under scrutiny. This sort of evidence is straightforward to obtain from observational data from representative samples and does need not come from genetically informative data.

Criterion 2. Second, it is important to consider whether the noncognitive factor predicts achievement *incremental* to intelligence and the major dimensions of individual differences in personality known as the Big Five. The term "noncognitive" specifically implies that the factor not only represents something other than cognitive ability, but has effects on achievement that are unique of cognitive ability. Moreover, as described below, myriad specific noncognitive factors have been mentioned in the literature, and it would be useful to ascertain whether they represent something other than the Big Five personality traits, or are conversely "a rose by any other name."

Criterion 3. Third, because we predict that genotypes become matched with educationally-relevant environments via the effects of genes on noncognitive factors, the noncognitive factor should be, to some degree, heritable. This sort of evidence requires data from a genetically informed study, such as a twin or adoption study.

Criterion 4. Fourth, there should be a non-zero genetic correlation between the noncognitive factor and academic achievement. In other words, the genetic variants that influence the noncognitive factor should also be associated with variation in achievement. As formalized by Dickens and Flynn (2001), transactional models require that environmental experiences occur persistently and/or recurrently over time in order to have appreciable effects on achievement outcomes. Environments that are evoked, selected, and attended to on the basis of genetically influenced factors, which are themselves highly stable over time (Tucker-Drob & Briley, 2014; Briley & Tucker-Drob, 2014), are therefore most likely to occur with sufficient stability and persistence to have appreciable effects on achievement outcomes. This sort of evidence also requires data from a genetically informed study.

Criterion 5. Fifth, the direction of causation should be, at least partially, from the noncognitive factor to achievement. Direction of causation can be evaluated, for example, via a cross-lagged panel model applied to longitudinal data on both the noncognitive factor and achievement. Data that are both longitudinal and genetically informative are particularly valuable here because such data allow one to estimate the extent to which a longitudinal effect is genetically mediated; e.g., Tucker-Drob & Harden, 2012c). Additional, co-occurring causation from achievement to the noncognitive factor would also be consistent with the transactional model, and such bidirectional causation could serve to amplify early genetic variation. Experimental evidence that interventions that targeting a specific noncognitive factor also influence achievement would also be relevant to Criterion 5, in demonstrating that the changes in the noncognitive factor *can* cause changes in achievement. Such evidence, however, would not necessarily be indicative that naturally occurring genetic variation in the noncognitive factor causes individual differences in achievement.

Criterion 6. Sixth, environmental experiences relevant for achievement should mediate the causal effect of noncognitive factors on achievement *via genetic pathways*. In principle, this prediction can be tested in a multivariate behavioral genetic design, in which the noncognitive factor, achievement, and the environmental experiences relevant for achievement are all measured. Unfortunately, however, identifying and measuring the many experiences relevant for achievement may be a herculean task, particularly, if the individual effects of specific environmental experiences are themselves small (cf. Turkheimer & Waldron, 2000). As Tucker-Drob & Briley (2014) have previously proposed, "if the environments relevant for cognition are those that result from stable and enduring gene–environment correlation processes (Dickens & Flynn, 2001), it may be the case that efforts to measure genetically influenced psychological tendencies to engage with a host of stimulating experiences [i.e. noncognitive factors] will prove to be more fruitful—albeit less direct—for indexing cumulative environmental effects than efforts to measure the experiences themselves."

With these criteria in mind, we now review current evidence regarding gene-environment transactions involving an array of noncognitive factors, including: (1) Big Five personality traits, (2) intellectual interest, (3) academic interest; (4) self-perceived ability; (5) grit; (6) self-control / impulse control; (7) achievement goal orientations (mastery / performance); (8) intelligence mindsets / implicit theories of intelligence; and (9) expectancies and values.

Big Five Personality Traits

The "Big Five" personality trait taxonomy has become the dominant dimensional account of personality for the past quarter century (John, Naumann, & Soto, 2008). The factors (Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism) represent individual differences in patterns of thinking, feeling, and behaving that are relatively stable across time and context. These factors, which have been well-replicated across many different samples and testing formats, were not specifically derived from research on academic achievement, or research in any specific domain of life for that matter, but were instead derived from research seeking to describe the entire range of human personality across domains of life. The Big Five trait dimensions are therefore necessarily broad, and do not purport to capture all of the more nuanced, or context-specific, aspects of behavior. They serve as a sensible starting point in the search for non-cognitive correlates of academic achievement.

The two Big Five traits that have been consistently linked with achievement are Conscientiousness and Openness. Conscientiousness refers to a general tendency to be organized, planful, and effortful in one's goals and duties. Openness, also commonly termed Intellect, refers to a general tendency to be interested in ideas and creative pursuits. In a comprehensive meta-analysis of the relations between the Big Five and academic achievement, Poropat (2009) reported that Conscientiousness and Openness were correlated with achievement (typically course grades or overall grade point average) at .22 and .12, respectively. IQ was correlated with achievement at .25. Controlling for intelligence did not appreciably reduce personality-achievement associations. Thus the evidence regarding Conscientiousness and Openness meets Criterion 1 (correlated with achievement) and Criterion 2 (correlated with achievement incremental to IQ).

Of all of the noncognitive factors surveyed in the current article, it is likely that the Big Five are the factors that have been most extensively studied in behavioral genetic research designs. A number of surveys of the behavioral genetic literature on personality exist, and they largely agree in placing the overall magnitude of heritability for each of the Big Five traits at between approximately .40 and .50 (Bouchard & Mc Gue, 2003). Moreover, a recent meta-analysis of longitudinal behavioral genetic studies of personality (Briley & Tucker-Drob, 2014) indicated that genetic factors moderately contribute to longitudinal rank-order stability in Big Five personality traits across nearly the entire lifespan, from infancy to old age. Criterion 3 (the noncognitive factor is heritable) is clearly met for all Big Five traits.

A handful of studies have presented evidence relevant to Criterion 4. In twin and extended family design consisting of 650 families, Luciano, Wainwright, Wright, & Martin (2006) reported that variance shared between two facets of Conscientiousness (Competence and Dutifullness) and scores on measures of verbal IQ, performance IQ, and academic achievement was primarily explained by a common genetic factor. In what appears to have been a largely overlapping sample, Wainwright et al. (2008) reported positive genetic correlations between multiple facets of Openness and verbal IQ, performance IQ, academic achievement, and processing speed. Thus there is support for criterion 4 (nonzero genetic correlation between the noncognitive factor and achievement) for both Conscientiousness and Openness.

Evidence regarding Criteria 5 and 6 is more tentative. With respect to Criterion 5 (causation from the noncognitive factor to achievement), there have been relatively few longitudinal studies of the relation between personality and later academic achievement, and it appears that those that do exist have not controlled for previous levels of academic achievement, as could be achieved in a cross-lagged approach (Chamorro-Premuzic & Frunham, 2003; Heaven, Ciarrochi, & Vialle, 2007). A meta-analysis by Richardson, Abraham, and Bond (2012), reported that Conscientiousness remained predictive of college GPA after controlling for both SAT/ACT and high school GPA, but it is not clear whether the studies contributing the meta-analysis measured Conscientiousness prior to, or concurrent with, college attendance. The former would be better evidence of a (prospective) directional association from Conscientiousness to achievement. With respect to Criterion 6 (environmental experiences relative to achievement should mediate the causal effect of noncognitive factors on achievement via genetic pathways), we are not aware of any behavioral genetic studies of the big five personality traits and academically-relevant environmental experiences. However, there is support for genetically-mediated longitudinal associations between personality and life events more generally. For example, in a study of 338 adult twin pairs, Kandler, Bleidorn, Reimann, Angleitner, & Spinath (2012), found that associations between personality and life events were "primarily directional from personality to life events, and basically genetically mediated." Thus, there is circumstantial evidence in support of criterion 6 for personality.

Intellectual Interest / Intellectual Curiosity

Although measures of the Big Five personality traits are the most popular personality measures in differential psychology, social and educational psychologists who are specifically interested in understanding cognitive development and academic achievement have developed and implemented an array of more narrow noncognitive measures to specifically tap behavioral tendencies more directly tied to achievement.

Von Stumm, Hell, & Chamorro –Premuzic (2011) proposed that *intellectual curiosity* is the "third pillar of academic performance," after intelligence and conscientiousness. Intellectual curiosity refers to the desire to think, reason, learn, and understand. It also includes a preference for, enjoyment of, and history of engaging in thinking, reasoning, and learning behaviors. Intellectual curiosity is commonly measured with Ackerman's Typical Intellectual Engagement (TIE; Goff & Ackerman, 1992) scale and

Cacioppo's Need for Cognition scale (Cacioppo & Petter, 1982). These scales lack discriminant validity from one another (Mussel, 2010; Woo, Harms, & Kuncel, 2007), but are distinguishable from (albeit correlated with) Openness. Regarding Criterion 1, Von Stumm et al. (2011) report a meta-analytic correlation of .33 between TIE and academic performance (grade point average or an achievement test composite). Supporting Criterion 2, TIE remained uniquely associated with academic performance after controlling for openness, conscientiousness, and intelligence.

Compared to the Big Five, much less behavioral genetic research has been done on intellectual interest. One study (Tucker-Drob & Harden, 2012) reported that intellectual interest was 27% heritable (Criterion 3), and that genetic factors mediated approximately one third of the correlation (r = .44) between intellectual interest and academic achievement (Criterion 4). Regarding Criterion 5, there does not appear to be research that has employed longitudinal models to test for direction of causation between intellectual interest and achievement, although there has been evidence of this type for academic interest (Marsh et al., 2005, described below). With respect to Criterion 6, we are not aware of behavioral genetic studies that have directly examined associations between intellectual interest and academically-relevant learning experiences.

Academic Interest

It is unclear whether academic interest is distinguishable from intellectual interest, and the two terms are often used interchangeably. It is possible that the term academic interest allows for more domain specificity, i.e. for different self-concepts in math, science, and reading. Supporting Criterion 1, a meta-analysis by Schiefele et al. (1992) placed the magnitude of the domain-specific interest-achievement association at an average of .31, ranging from .16 to .35, with the magnitude differing somewhat by domain (e.g. mathematics vs. literature). In a large sample of approximately 375,000 American high schoolers, Tucker-Drob and Briley (2012) similarly estimated the average magnitude of the domain-specific interest-achievement association to be .31, ranging from .22 to .44 depending on the domain (e.g. art, biological sciences, literature), with the exception of .07 for hunting/fishing, with associations persisting at nearly full strength after controlling for intelligence (Criterion 2).

In a study combining data from nearly 13,000 twins ages 9-16 years from six different countries, Kovas et al. (2015) reported that the heritability of subject-specific enjoyment (e.g. Reading, Math, and English) was consistently estimated at approximately 40% across subsamples (Criterion 3). There is also evidence from longitudinal research supporting Criterion 5. For instance, Marsh et al (2005) used cross-lagged longitudinal models to test the direction of causation between academic interest (math interest) and academic achievement (math grades and test scores). Results indicated a stronger standardized effect from interest to later achievement (controlling for past achievement) than from achievement to later interest. There does not appear to have been research on academic interest directly relevant to Criteria 4 and 6.

Self-Perceived Ability

Self-perceived ability, self-assessed intelligence, and academic self-concept are all closely related constructs that may be measured using domain general or domain-specific (e.g. math self-concept, reading self-concept) levels. As well-summarized by Chamorro-Premuzic, Harlaar, Greven, & Plomin (2010), these noncognitive factors may relate to achievement through “both ‘insight’ (children's accounts of their previous performance) and self-efficacy (the self-fulfilling or motivational effects of self-beliefs).”

This general set of constructs is among the noncognitive factors most studied using longitudinal methods. For instance, Marsh and Craven’s (2006_ review of results from a number of studies that have applied latent variable cross-lagged panel models presented evidence for a “reciprocal-effects model,” in which academic self-concept predicts later achievement above and beyond previous levels of achievement, *and* achievement predicts later academic self-concept above and beyond previous levels of academic self concept (Criterion 5). Chamorro-Premuzic et al. (2010) have also reported evidence for reciprocal effects between self-perceived ability and achievement in a latent variable cross-lagged panel analysis, even after controlling for general cognitive ability at each wave (Criteria 2 and 5). Using data from nearly 13,000 children ages 9-16 years from six different countries, Kovas et al. (2015) reported that the heritability of subject-specific self-perceived ability was consistently estimated at approximately 40% across subsamples (Criterion 3). Moreover, consistent with the predictions of a transactional model, Greven, Harlaar, Kovas, Chamorro-Premuzic, and Plomin (2009) found that the associations between self-perceived ability and both concurrent achievement and later achievement, independent of IQ, were genetically mediated (Criteria 1, 2, 4 and 5). We are not aware of research on self-perceived ability relevant to Criterion 6.

Grit

Grit refers to the tendency to take actions toward a prioritized goal (such as high academic achievement), in the face of challenges or temptations to do otherwise. Grit has been found to be highly related to, albeit distinguishable from, Conscientiousness (Duckworth et al., 2007), and has been linked with achievement even when IQ or SAT are controlled (Duckworth et al. 2007; Criteria 1 and 2), although this link may not persist after controlling for conscientiousness (Ivcevic and Brackett, 2014; possible failure of Criterion 2). We are aware of no genetically informed work on grit, so there is currently no evidence regarding Criteria 3, 4, or 6. We are also not aware of longitudinal research on the relation between grit and achievement that has controlled for previous levels of achievement, so there does not appear to be evidence relevant to Criterion 5.

Impulse Control / Self-Control

Self-control (also described as impulse control, inhibitory control, inhibition, or – when conceptualized in the opposite valence – impulsivity) has been distinguished from grit primarily in terms of timescale. As Duckworth and Gross (2014) write, “self-control entails aligning actions with any valued goal despite momentarily more-alluring alternatives; grit, in contrast, entails having and working assiduously toward a single challenging superordinate goal through thick and thin, on a timescale of years or even decades.” Additionally, whereas grit is typically measured with a self-report instrument, self-control has been measured in myriad ways, ranging from self-report to performance-based measures. Importantly, measurement of impulse control has suffered from both the “jingle” and “jangle” fallacies (Whiteside & Lynam, 2000). Impulse control is, in fact, a highly complex construct that has been variably organized into four (Whiteside & Lynam, 2001), five (Cyders et al., 2007), or even eight different dimension (Nigg, 2000). Moreover, self-report measures of impulse control correspond weakly – if at all

– with performance-based measures (Cyders & Coskunpinar, 2011; Dick et al., 2010), and different performance measures are variably related to different underlying neural systems (Jentsch et al., 2014). Moffitt and colleagues (2011) combined multiple, longitudinal measures of self-control (including observational ratings of behavior in a testing situation in early childhood, and parent and teacher ratings on impulsivity scales in middle childhood) and found that self-control prospectively predicted academic achievement, even after controlling for IQ (Criteria 1, 2, and possibly 5). Duckworth and Seligman (2005) found that a "self-discipline" composite formed from self-report, parent-report, and teacher-report measures of impulsivity and self-control longitudinally predicted GPA above and beyond IQ and earlier GPA (Criteria 1, 2, and 5). Additionally, various measures of self-control have been found to be heritable (Criterion 3), including both performance-based measures (Friedman et al., 2008) and self-report measures (Ellingson, Verges, Littlefield, Martin, & Slutske, 2013). We are not aware of research on self-control that is directly relevant to Criteria 4 or 6.

Achievement Goal Orientations

A number of related theoretical frameworks (Kaplan & Maehr, 2007; Meece, Anderman, & Anderman, 2006) generally conceptualize achievement goals as falling along two distinguishable dimensions. The *mastery goal orientation* dimension distinguishes individuals by how motivated they are to engage with education for the purposes of learning the material and increasing their competence, whereas the *performance goal orientation* dimension distinguishes individuals by how motivated they are to engage with education for the purposes of appearing competent to others and visibly outperforming their classmates. Mastery goals are generally found to be positively associated with academic achievement, whereas results have been inconsistent for performance goals, with many articles reporting negative associations and many others reporting positive associations. A meta-analysis by Hulleman, Schrager, Bodmann, & Harackiewicz (2010) indicated that inconsistences in previous research might be attributable to differences in the content of the specific measures used. Nevertheless, the absolute magnitudes of associations between goal orientations and academic performance were generally estimated to be low, i.e. in the vicinity of an absolute correlation of .10 (Criterion 1). A meta-analysis of correlates university student's academic performance by Richardson et al.(2012) indicated that goal orientations were cross-sectionally associated with achievement at r=.15 and prospectively associated with achievement at r=.09, although the extent to which the studies contributing to the prospective meta-analytic estimate controlled for baseline achievement (as would be required for Criterion 5) is not clear.

Very little behavioral genetic work appears to have been conducted on achievement goal orientations. The only such study that we are aware of is that of Murayama, Elliot, & Yamagata (2011), who used data from Japanese twins to estimate the heritability of performance goals at approximately 40% (Criterion 3), with the remaining variation attributable to the nonshared environment. There appears to be no behavioral genetic evidence relevant to Criteria 4 and 6.

Intelligence Mindsets/Implicit Theories of Intelligence

Dweck and colleagues (Dweck & Leggett, 1988, Dweck, 1999) have proposed a motivational model of achievement that is based on children's lay "theories" or "mindsets" about whether intelligence is fixed (an "entity theory") or malleable (an "incremental theory"). Intelligence mindsets are typically measured with a unidimensional scale, with entity and incremental mindsets occupying polar extremes. Because they view intelligence as something that can be changed with hard work, children with incremental mindsets are thought to put more effort into learning. Conversely, because they are more likely to view effort as futile for improving intelligence, children with entity mindsets are thought to put less effort into learning. Dweck and colleagues (e.g. Blackwell, Trzesniewski, & Dweck, 2007) have reported that naturally occurring variation in mindsets is predictive of later changes in academic achievement (Criteria 1 and 5), and that interventions to teach incremental theories of intelligence improve achievement outcomes. We are aware very little behavioral genetic work on intelligence mindsets. For instance, a study by Spinath, Spinath, Riemann, & Angleitner, 2003 examined intelligence mindsets in twins, but did not report results of behavioral genetic analyses. There therefore does not appear to be evidence relevant to Criteria 3, 4, and 6.

Expectancies and Values

Eccles' theory of academic effort and motivation focuses on the intersection of expectancies and values (Wigfield & Eccles, 2000; Nagengast, Marsh, Scalas, Xu, Hau, & Trautwein, 2011). *Expectancies* refer to the student's expectations that they are capable of succeeding academically, and *values* refer to the student's perception that academic success is a desirable goal. Expectancies and values have been measured in a number of different ways, and it is likely that expectancies and values are each themselves multidimensional. In fact, a number of the constructs reviewed above have been classified as forms of expectancies and values (see, e.g., Hulleman, Barron, Kosovich, & Lazowski, 2014). For example, self-perceived ability can be construed as an expectancy regarding success. Additionally, the expectancy-value theory highlights other sorts of constructs not previously discussed. For instance, students' perceptions about the value of education for success in life, their educational attainment goals, and their expectations regarding their ultimate levels of educational attainment are key constructs in the Expectancy-Value model that have been linked with academic achievement .

The Expectancy-Value model is supported by evidence linking expectancies and values (along with their interactions) to motivation and academic achievement (Wigfield & Eccles, 2000; Nagengast et al. 2011; Criterion 1), including cross-lagged longitudinal evidence of reciprocal associations between expectancies and values and achievement (Zhang et al., 2011; Criterion 5). There is also evidence that at least some expectancy and value measures predict achievement above and beyond intelligence (Spinath et al., 2006; Criterion 2). Perhaps because the model is largely set up as a socialization model, (Wigfield, Eccles, Fredricks, Simpkins, Roeser, & Schiefele, 2015), very little behavioral genetic work has been conducted under the Expectancy-Value framework. One exception comes from Briley, Harden, and Tucker-Drob (2014), who used both behavioral genetic and cross-lagged longitudinal models to demonstrate that *parental* educational expectations for their children's ultimate educational attainment (which, in Expectancy-Value theory is theorized to be key mechanism through which parents instill educational expectancies in their children; Jacobs & Eccles, 2000) are both predictive of their children's academic achievement and educationally-relevant behaviors *and* sensitive to genetically-influenced individual differences in child achievement and educationally-relevant behaviors. However, we are aware of no behavioral genetic work on *child* noncognitive factors that has been conducted explicitly in the context of the Expectancy-Value model. Tests of Criteria 3 and 4 are therefore lacking. One relative strength of research conducted in the context of the Expectancy-Value model is that researchers often used expectancies and values to predict academically-relevant experiences, such as course enrollment and extracurricular activity involvement (e.g. Nagengast et al., 2011; Meece, Wigfield, & Ecccles, 1990), partially fulfilling Criterion 6.

Summarizing the Empirical Evidence on Noncognitive Factors

The research supporting the role of noncognitive factors in gene-environment transactions is summarized in Table 1. As described in the section above, different constructs and measures vary in the extent to which they are correlated with academic achievement, the extent to which this correlation has been tested in longitudinal designs capable of disentangling causation from reverse causation, and the extent to which they have been examined using genetically informative methods. Currently, self-perceived ability and intellectual interest are the noncognitive factors with the most evidence supportive of their roles in academically-relevant gene-environment transactions. Perhaps not coincidently, these are also the two noncognitive factors that have been most systematically studied using both longitudinal and genetically informative designs.

Suggestions for Future Research

Genetic differences between people matter for how well they perform in school settings. At the same time, children are clearly more likely to succeed academically if they experience high-quality home and school environments. A rich and varied theoretical literature has proposed that genes, noncognitive skills, cognitive ability, environmental experiences, and academic achievement are linked in a reciprocal and dynamic system. According to this proposal, children who are conscientious and open to new experiences, who like thinking about abstract ideas and who don't give up when frustrated, experience different types of environments than children without these skills. They are given more positive attention from teachers, are placed into more challenging classes, read more books, spend more time and effort on difficult problems, and interpret their successes and failures differently. Because individual differences in

Table 1. Status of empirical support for specific noncognitive factors as mechanisms of gene-environment transactions for academic achievement.

	Criterion 1	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Criterion 6**
Noncognitive Factor	*Correlated with academic achievement*	*Correlated with achievement incremental to IQ*	*Heritable*	*Genetic association with achievement*	*Longitudinally predicts achievement (controlling for past achievement)*	*Genes ➔ noncognitive factor ➔ environment ➔ achievement*
Conscientiousness	+	+	+	+	~	
Openness	+	+	+	+	~	
Intellectual Interest	+	+	+	+		
Academic Interest	+	+	+		+	
Self-Perceived Ability	+	+	+	+	+	
Grit	+	+				
Self-Control / Impulse Control	+	+	+		+	
Mastery Achievement Goal Orientations	+				~	
Performance Achievement Goal Orientations	~		+		~	
Intelligence Mindsets / Implicit Theories of Intelligence	+				+	
Expectancies and Values	+	+			+	~

Note: + = positive empirical support for criterion identified in the current literature review. ~ = mixed or incomplete empirical support for criterion identified in the current literature review. Empty cells = no direct tests of the criterion identified in the current literature review.

these noncognitive skills are expected to be at least partially due to genetic differences between people, when noncognitive skills shape a child's environmental experiences, this process results in gene-environment correlations – children with certain genotypes are more likely to experience certain environments. If genotypes are matched to environments, and environments have causal effects on both achievement and noncognitive skills, the net result of this process will be high heritability estimates for achievement – not in spite of the environment, but through the environment (Tucker-Drob et al., 2013).

Importantly, despite the considerable appeal of this theoretical model, and its recurrence in the literature over several decades, no study to-date has tested a comprehensive model of the links between genes, noncognitive skills, environmental inputs, and achievement in a longitudinal, genetically-informative study. This hole in the empirical literature is probably due, at least in part, to disciplinary divides: Researchers in developmental, educational, and social psychology who focus on understanding children's motivations for learning and on measuring the quality of their academic experiences often view behavioral genetics research with some suspicion (if not outright hostility). At the same time, behavioral genetic researchers have commonly conceptualized gene-environment correlations as a source of confounding that creates illusory correlations between environmental experiences and important life outcomes, rather than as a key mechanism for the emergence of heritable variation in academic achievement. Interdisciplinary research that pays attention to both behavioral genetic theory and research design, *and* to recent developments in the measurement of noncognitive skills and academically-relevant environments, will be necessary to understand the dynamic nuances of gene-environment transactions.

This paper has focused on gene-environment correlations, in which individuals with certain genotypes are more likely to experience certain environments. In contrast, gene-environment *interaction*, or G×E, implies that individuals with different genotypes differ in their response to environment inputs (e.g., are more vulnerable to adverse environments or sensitive to enriching ones), *and* that genotypes are more potent predictors of phenotypes in certain environments. Although the existence of gene-environment correlation does guarantee the existence of gene-environment interaction (and vice versa), gene-environment correlation may be, in some cases, a key mechanism driving G×E interactions on academic achievement (Tucker-Drob et al., 2013; Turkheimer & Horn, 2014). As we have described, the transactional model predicts that children will differentially select, evoke, and attend to environment inputs on the basis of their genetically-influenced traits, including both initial cognitive abilities and noncognitive skills. Importantly, however, this process of genotype-environment matching depends on there being an array of potential environmental inputs. For a motivated child to read, she needs access to a library. In macro-environmental contexts (e.g. schools, neighborhoods, social classes) in which there is a more limited “cafeteria” of proximal learning experiences from which to choose, individual differences in preferences and interests are expected to have less relevance for the sorts of proximal environments that are experienced, and hence less relevance for cognitive development and academic achievement. This decoupling between genetically-influenced noncognitive factors and environmental inputs will result in diminished heritable variation in cognition and achievement in certain macroenvironmental contexts. Consistent with this proposal, we have found that both domain-general and domain-specific interest is more strongly predictive of knowledge and achievement outcomes in socioeconomically advantaged family, school, and national contexts (Tucker-Drob, Cheung, & Briley, 2014; Tucker-Drob & Briley, 2012). Moreover, in genetically informative samples, we have found that this interaction with socioeconomic status occurs on the genetic link between interest and achievement: genetic variation in interest is more strongly predictive of achievement under conditions of (family-level) socioeconomic advantage (Tucker-Drob & Harden 2012a, 2012b).

Importantly, it is not necessarily the case that all noncognitive factors interact with socioeconomic status, or other markers of environmental opportunity, in the same way. We have focused our previous research on primarily on interest, but other factors, such as grit or implicit theories of intelligence, could interact with macroenvironmental contexts according to altogether different patterns, or not at all. For instance, while interest is *more* predictive of achievement in more advantaged contexts, self-regulatory behaviors (e.g. grit, impulse control) may be *less* predictive of achievement in more advantaged contexts, which contain external behavioral scaffolds for positive approaches toward learning. Thus, we caution researchers interested in testing developmental theory against treating noncognitive factors as interchangeable measures or treating any single measure as a "model phenotype" (Briley & Tucker-Drob, 2015).

Conclusions

Across the past half-century, a variety of theorists – including Hayes (1962), Cattell (1987), Scarr and McCartney (1983), Bronfenbrenner and Ceci (1994), Dickens and Flynn (2000), Johnson (2010), Turkheimer and Horn (2014), and ourselves (Tucker-Drob et al., 2013; Tucker-Drob & Harden, 2012a, 2012b, 2012c) – have posited that heritable individual differences in cognitive ability and academic achievement emerge and widen via dynamic, reciprocal transactions between children's genetically-influenced abilities and their specific environmental experiences. The current chapter contributes to this literature by integrating behavioral genetic theories of gene-environment correlation with insights from social, developmental, and educational psychology regarding how to conceptualize and measure a diverse array of noncognitive skills. These noncognitive factors may operate as "experience producing drives" (Hayes, 1962) and thus act as critical intermediaries in the process of gene-environment matching; however, as we have reviewed here, there is a paucity of behavioral genetic research on noncognitive factors that directly tests this hypothesis. Our interdisciplinary synthesis points to the importance of longitudinal, genetically-informed research that incorporates careful measurement not just of ability and achievement, but also noncognitive factors and environmental experience. Such research is critically necessary to provide a more complete understanding of the developmental mechanisms that give rise to individual differences in cognitive development and academic achievement.

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