Published in final edited form as:

Learn Individ Differ. 2007 ; 17(3): 201–219. doi:10.1016/j.lindif.2007.04.004.

How Parents Influence School Grades: Hints from a Sample of Adoptive and Biological Families

Wendy Johnson^{1,2}, Matt McGue^{2,3}, and William G. Iacono²

¹ Department of Psychology, University of Edinburgh, Scotland, United Kingdom

² Department of Psychology, University of Minnesota, Twin Cities

³ Department of Epidemiology, University of Southern Denmark, Odense, Denmark

Abstract

Using the biological and adoptive families in the Minnesota-based Sibling Interaction and Behavior Study, we investigated the associations among genetic and environmental influences on IQ, parenting, parental expectations for offspring educational attainment, engagement in school, and school grades. All variables showed substantial genetic influence, and very modest shared environmental influence. No gender differences were evident. There were significant genetic influences common to IQ and parental expectations of educational attainment, parenting and engagement in school, school grades and engagement in school, parental expectations for offspring educational attainment and school grades, and IQ and school grades. A possible interpretation of the common genetic influences involving parenting is that parents use their own experience with school in shaping the ways in which they parent their offspring.

Among developmental and clinical psychologists, parenting is considered to be an important influence on children's academic outcomes (e.g., Gadeyne, Ghesquiere, & Onghena, 2004; Steinberg, Elmen, & Mounts, 1989). This is supported by a large volume of evidence from longitudinal (e.g., Steinberg, Lamborn, Darling, Mounts, & Dornbusch, 1994) and experimental intervention studies (e.g., Forgatch & DeGarmo, 1999), as well as by studies of concurrent associations. Investigations of the mechanisms by which parents exert their effects on academic outcomes tend to follow one of two general traditions (Kellaghan, Sloane, Alvarez, & Bloom, 1993): examination of the effects on children of parental actions, or "what parents do", and exploration of the effects on children of "who parents are". The classic parenting research focusing on socialization activities by parents in the form of emotional tone, disciplinary practices, responsiveness, and expectations (e.g., Baumrind, 1991; Maccoby & Martin, 1983) comes from the "what parents do" tradition, as does research on the quality of the home learning environment provided to children (e.g., Bradley, 1994; de Jong & Leseman, 2001). The "who parents are" tradition is represented by studies positing that socioeconomic and cultural factors carry with them trait-like parental socialization practices with a variety of contextual influences that affect development (e.g., Gallimore & Goldenberg, 2001; Gutman & McLoyd, 2000). Of course, the two research traditions do not necessarily reflect distinct

Corresponding author: Wendy Johnson, c/o Department of Psychology, University of Minnesota – Twin Cities, 75 East River Road, Minneapolis, MN 55455, 952-473-1673, wendy.johnson@ed.ac.uk.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

aspects of parenting, as who parents are and what they do are often closely intertwined, and may be especially so with respect to their offspring's academic achievement.

Using coevolution to combine the two parenting research traditions

One way to bring together the two parenting research traditions is to think of parenting activities as mechanisms of coevolution. This is the name given to the process by which biological and cultural inheritance factors transact to result in transmission of culturally influenced behaviors and attitudes from one generation to the next through modification of natural selection pressures (Cavalli-Sforza & Feldman, 1981; Durham, 1979). It is thus a form of gene-environment correlation. In addition, however, it includes explicit recognition that the active and evocative aspects of gene-environment correlation, in which the individual seeks out and evokes environmental experiences that are compatible with genetically influenced traits, create selective pressures to form adaptive niches within broader groups of individuals (Johnson, 2007). The coevolutionary process is facilitated because, in most families, the same parents transmit both genetic and cultural influences.

The existence of coevolution has been documented extensively in non-human species, and in humans as well (Laland, Kumm, Horn, & Feldman, 1995). For example, the culturally transmitted domestication of cattle and development of dairying activities and cheese-making processes, taking place over generations, likely altered the environments of self-selected groups of humans sufficiently to select for genes which confer greater adult lactose tolerance today (Aoki, 1986). This example dramatizes the point that culture by definition entails some collection of transmission systems that together provide humans with an extra-genetic inheritance system based on knowledge (Cavalli-Sforza & Feldman, 1981). Often, the knowledge takes the form of social learning (language, standards of conduct, values, technology). There is evidence that the ability to make use of these learned behaviors is evolutionarily adaptive (Betzig, Bergerhoff Mulder, & Turke, 1988; Chagnon & Irons, 1979), suggesting genetic involvement in the transmission of cultural processes.

Genetic involvement in the transmission of cultural processes could take either or both of two basic forms. First, there might be genes that predispose learning processes toward the acquisition of adaptive information (Durham, 1979). Learning predispositions of this type are well documented in animals, and there is evidence for them at least in human perception (e.g., Fantz, Fagan, & Miranda, 1975). Such predispositions may help humans to identify what is relevant and adaptive from the range of presented environmental stimuli. Thus, for example, children who all possess these adaptive-information-seeking genes but who differ genetically in other ways might make very different uses of the information presented to all of them in the form of schooling. To the extent this is the case, we should expect genetic influences on school engagement and performance. Evidence for such influence has been reported (Bartels, Rietveld, Baal, & Boomsma, 2002; Johnson, McGue, & Iacono, 2005, 2006).

The second form of genetic mediation of cultural processes involves the possibility of genes that predispose parenting processes toward the teaching of information that they believe will prove adaptive to their children (Perusse, Neale, Heath, & Eaves, 1994) because they found it to be adaptive. Because this knowledge is necessarily context-dependent, these teaching predispositions may also vary considerably. Their own experience with schooling might be one aspect of their overall life experience that parents use to orient their offspring with respect to school and to guide them in responding to the demands of schooling. For such teaching predispositions to be operative, it is of course necessary that parental rearing practices be under genetic influence. Several researchers have provided evidence for this (e.g., McGue, Elkins, Walden, & Iacono, 2005a; Perusse, et. al. 1994), but it is important to develop further evidence. In addition, if such parental teaching predispositions are important in adaptation to schooling,

there should be links between the genetic influences on parenting and offspring engagement and performance in school. One of the purposes of this study was to estimate the extent of genetic influences on parental rearing practices and engagement in school and the extent to which these genetic influences were linked.

Most parents have expectations about their children's eventual educational attainment (Glick & White, 2004; Kaplan, Liu, & Kaplan, 2001), and there is evidence that this is another mechanism through which parents influence their offspring's school performance (Ganzach, 2000; Kaplan, Liu, & Kaplan, 2004). Because of the importance many people accord to educational attainment in developing career and economic opportunities, many parents develop clear expectations that their offspring will attain a certain level such as college graduation regardless of whether the parents had the opportunity to do so themselves (Glick & White, 2004). At the same time, parents who did not adapt well to school may have relatively low expectations that their offspring will do any better (Kaplan et al., 2004). It is also possible that parental expectations themselves may be influenced by characteristics of the offspring. That is, parents may "read" their offspring's apparent academic ability and school performance and modify their expectations accordingly. To the extent that parents' general expectations based on their own experience with school directly influence their offspring's school performance in similar ways, we should expect shared environmental influences on parental expectations for academic attainment, because parents tend to try to provide their children with equal opportunities for education, all else being equal (Behrman, Pollak, & Taubman, 1995). To the extent that offspring characteristics influence parental expectations, we should expect parental expectations to show genetic influences, reflecting at least in part genetically influenced characteristics of the child. Thus, these genetic influences on parental expectations should also have strong links to genetic influences on child school performance and to genetic influences on characteristics related to school performance such as intelligence (Ceci & Williams, 1997). A second purpose of this study was to measure the extent of these links.

The role of engagement in school performance

Engagement, sometimes called motivation or effort, has commonly been linked to school performance. A substantial body of research (e.g. Dweck, 2002; Eccles, Roeser, Wigfield, & Freedman-Doan, 1999) has been devoted to the identification of specific aspects of and factors contributing to engagement under the assumption that the link between engagement and school performance (Gottfried & Gottfried, 1996) is independent of academic ability or intelligence. This assumption has been tested, but only relatively rarely (e.g., Aspinwall & Taylor, 1992; Gagne & St. Pere, 2001; Lloyd & Barenblatt, 1984). Results have generally indicated that engagement does make some contribution to school performance, but its contribution independent of intelligence is small. The degree to which this is due to correlation between the two is far from clear (Shore, Cornell, Robinson, & Ward, 1991). Interaction effects of engagement and intelligence have also been investigated, but no consistent findings have been obtained (Anastasi & Urbina, 1997).

Engagement has typically been thought to develop from the experience of competence in the school environment, initiated and augmented by parental influences in the form of parenting practices and level of involvement (e.g., Eccles & Harold, 1996; Eccles et al., 1999). Thus, the influences on engagement have been assumed to be largely environmental in nature and to contribute to making family members more similar, in spite of the facts that, in most families, parents provide genetic as well as environmental influences on offspring and there is evidence for genetic influence on engagement (Johnson, et al., 2006), which also tend to make family members more similar. The proposition that parents' influence on engagement is primarily environmental can be pitted against the proposition developed above that offspring engagement arises in part from genetic influences held in common between parents and offspring. The

propositions are not mutually exclusive, of course, so the evidence developed will reflect the relative importance of the two propositions in explaining school performance. To the extent that parents provide environmental influences that have similar effects on the engagement of all their offspring, we should expect the correlations between engagement and parenting practices and expectations to be mediated by the environment shared by members of the same family. To the extent that offspring engagement arises from genetic influences common to parents and offspring, we should expect these correlations to be genetically mediated. To the extent that engagement contributes to school performance independently of intelligence, we should expect a small correlation between them, mediated by the environment not shared by members of the same family. A third purpose of this study was to investigate the associations among engagement and intelligence, parenting practices and expectations in order to evaluate the evidence for these competing propositions about the emergence and importance of engagement.

Most studies of the effects of parenting practices have tended to rely on samples of individual offspring growing up with their biological parents. Most studies estimating genetic and environmental influences have made use of samples of twins, again growing up with their biological parents. Neither is ideal for exploring the effects of parenting on school performance. Environmental effects of parenting are confounded with genetic effects in studies using individual offspring growing up with their biological parents (e.g., responsible and conscientious parents may have responsible and conscientious children because of both the genes they transmit and the rearing environment they provide). It is often difficult to disentangle genetic and shared environmental effects accurately in twin studies as well, because parents tend to have similar levels of educational attainment (Vandenberg, 1972), which implies some similarity in their experiences of adapting to school. At the same time, educational attainment tends to show genetic influence (Bouchard, 1984; Reynolds, Baker, & Pedersen, 2000). When parents are similar (that is, they mate assortatively) for a genetically influenced trait, biological parent-offspring and therefore sibling resemblance for that trait will be stronger than under conditions of random mating. In biometric modeling the greater genetic resemblance due to assortative mating will mimic environmental influences shared by family members that tend to make them similar. One solution to this is to make use of a sample of both biological and adoptive families, because any sibling resemblance in the adoptive families will be due to these kinds of shared environmental influences. In this study we made use of such a sample.

Gender differences in school performance

There are substantial mean gender differences in school performance as well as in individual characteristics associated with it and potentially in environmental influences upon it. In general, girls receive higher grades than boys and score more highly on achievement tests, from elementary school through college (e.g., Kimball, 1989; Mau & Lynn, 2001). This is in spite of the fact that boys tend to score slightly higher than girls on college and other aptitude tests (Mau & Lynn, 2001). One result of the better school performance by girls is that more girls than boys attend college at present in the United States (American Association of University Women, 1996). Effect sizes for the gender differences in school performance vary considerably, depending on the measure used and the age of the students, but can range as high as .5 standard deviation. Higher engagement may be one reason for girls' advantage in school performance (Hyde & Kling, 2001), as girls tend to respond more to the externally assigned value of an achievement task than do boys (Eccles, 1984). Parenting practices and parental expectations may also differ and/or have different effects on girls and boys. How these factors come together to result in higher school performance in girls than in boys is not well understood, however, and a fourth purpose of this study is to investigate possible gender differences in the relations under examination.

In summary, this study was motivated by four questions. First, are parental rearing practices and engagement in school under genetic influence, and, if so, how are the genetic and environmental influences on parenting and engagement and performance in school related? Second, are there genetic influences on parental expectations for offspring educational attainment, and, if so, how are they linked to genetic influences on child school performance and to genetic influences on characteristics related to school performance such as intelligence? The answers to these first two questions will provide evidence supporting or refuting the proposition that parents influence their offsprings' academic achievement through a coevolutionary process. Third, to what degree can the genetic and environmental influences on school engagement and academic ability or intelligence be considered independent, and how is each related to parenting? The answer to this question will help to articulate the pathways through which a coevolutionary process may operate. Finally, are there gender differences in these associations that can help us to understand the higher school performance in girls than in boys? We used the sample of biological and adoptive Minnesota families participating in the Sibling Interaction and Behavior Study (SIBS) to address these questions.

Method

Sample

SIBS was begun in 1998. It consists of a community-based sample of pairs of adoptive and biological siblings and their parents who completed a 5-hour in-person lab assessment. The adoptive sample was recruited in collaboration with three large Minneapolis-St. Paul adoption agencies. As is typical of current practices in such agencies, these agencies minimally screen prospective parents for commitment to raising a child, a modest minimum level of income, and willingness to undergo a criminal record check (though some criminal record does not preclude a placement). The participating parents were representative of those accepting infant placements from these agencies, but they were socioeconomically advantaged relative to Minnesota parents as a whole. Still, they were a diverse group, with educational attainment ranging from high school drop-out to PhD, and single parents, gay couples, divorced couples, and stably married couples all represented. The families were selected to include an adolescent between the ages of 10 and 21 ($m=14.9$, $sd=1.9$) who was adopted before age 2, and a second adolescent not biologically related to the first but within five years of his/her age. In most cases, the second sibling was also an adoptive offspring of the parents (adopted before age 2), but there were some cases in which the second offspring was the biological child of the parents. A majority of the adoptees were internationally placed (most from Korea), so ethnicity is confounded with adoption status, as most of the biological families were Caucasian. Ethnicity, however, was not independently associated with the variables used in this study. The biological sample was recruited using birth records for the same geographic area. Each biological family included an adolescent between the ages of 11 and 21 and born to both parents, and a second full biological sibling within five years of the age of the first. There was no attempt to match adoptive and biological families, in order to maximize the potential to generalize from the findings in this sample to other samples (Stoolmiller, 1999).

Among eligible families, 63% of the adoptive and 57% of the biological families agreed to participate. The difference in participation rates was not significant ($\chi^2(1 \text{ df}) = 3.42$, $p=.064$). Over 90% of mothers in eligible but non-participating families completed a brief telephone interview providing demographic and child mental health information, thus allowing some comparison between participating and non-participating families. Primary reasons given for not participating were the time demands of the study and privacy concerns. Importantly, the telephone interviews revealed few differences between participating and non-participating families. Participating and non-participating adoptive families did not differ in maternal or paternal education, maternal or paternal occupational status, percent of original parents

remaining married, or reported child behavioral disorders (learning disabilities, substance abuse, attention deficit disorder, depression). Participating and nonparticipating biological families differed on only one of these variables: participating mothers were more likely to have a college degree (43.8%) than were nonparticipating mothers (28.6%; $\chi^2(1 \text{ df}) = 10.0, p = .002$). Thus, although there was evidence for a small amount of positive selection in our sample of biological families, analysis of the nonparticipating families indicated that our samples of adoptive and biological families were generally representative of the populations of eligible families from which they were drawn. Adoptive parents did have higher socioeconomic status, greater education, and greater marital stability than did biological parents. They did not, however, differ from the biological families on the parenting measures described below.

To explore the representativeness of the sample of biological families further, we made use of the integrated public use microdata series (IPUMS) 1% random sample (Ruggles et al., 2004) from Census 2000 (McGue, et. al, 2005). We examined IPUMS Census 2000 individuals age 35–55 living in the broader Minneapolis/St. Paul metropolitan area with two or more of their own children to form a census-level sample comparable in family composition and geographical location to our sample of biological families. Individuals living with more than one of their own children are more likely to be college graduates than the general population of adults (and thus likely to have higher SES). This is probably associated with the financial and relationship stability necessary to maintain a family situation through the births of two children over a period of several years. Forty-seven percent of men and 39% of women had at least a college degree in the IPUMS Census 2000-based sample. This compared well with the 44% of dads and 44% of moms who had college degrees in our biological families. There appeared to be a small amount of positive selection in biological moms, a result similar to that of our analysis of non-participating families. There was little evidence from either source, however, that SIBS biological families were not generally representative of families consisting of parents living with more than one of their own children in the Minneapolis/St Paul metropolitan area. There remained the possibility, however, that the SIBS mothers' slightly higher level of education than the general population was associated with somewhat higher family SES. Table 1 summarizes the demographic information on the adoptive and biological samples, and Census-2000-based population sample.

The full sample providing data for the current study included 409 adoptive and 208 biological families, made up of 558 boys and 676 girls. Two adoptive families of girls provided data on only one sibling. One sibling's data in one family were eliminated because her IQ score suggested mental retardation. In the other family, one sibling's data were eliminated because we learned after the assessment that the two siblings were biologically related. Among the complete adoptive families, there were 96 pairs of boys, 148 pairs of girls, 104 opposite-gender pairs with an older boy, and 59 opposite-gender pairs with an older girl. Among the biological families, there were 62 pairs of boys, 68 pairs of girls, 40 opposite-gender pairs with an older boy, and 38 opposite-gender pairs with an older girl. All participating families completed a 5-hour in-person lab assessment, and completed a battery of self-report measures prior to the lab assessment.

Measures

School performance—SIBS collected much of the same data in the same manner as does the Minnesota Twin Family Study (MTFS). The overall procedure used in that study is described in greater detail in Iacono, Carlson, Taylor, Elkins, & McGue (1999). School grades were provided by as many as 3 reporters: siblings, parents, and teachers. Siblings and parents reported data by self-report questionnaires completed in our laboratories and at home, based on most recently received report cards. We obtained teacher reports by having siblings still in school nominate as many as 3 different teachers and asking these teachers to complete an

extensive questionnaire of student behavior and achievement, including grades. We did not solicit teachers' reports regarding siblings who had graduated from high school (about 10% of the sample).

SIBS did not collect data on actual grades due to the disparities in grading formats, procedures, and standards in the various school systems from which the participating families were drawn. Rather, parents, siblings, and teachers reported separately on student grades in language arts, math, social studies, science classes, and overall by indicating that the grades were much better than average (A's=4), better than average (B's=3), average (C's=2), below average (D's=1), or much below average (i.e., failing=0). Teachers thus reported both on grades they had themselves assigned as well as on their impressions of grades in other courses that they had probably never seen firsthand, rendering the teachers' reports overall likely roughly as accurate as the parent's and self reports. Still, for teachers' reports, the estimated internal consistency reliability for the grade reports was .86, and estimated inter-teacher agreement reliability was .75. We computed average teacher scores based on the number of teacher reports obtained for each sibling.

Overall, the correlations among the grade reports for the three categories of reporters were high, with an average correlation of .72. For this study, we made use of the same form of composite reported grades as we did in MTFs (Johnson et al., 2006). That is, we averaged the reported grades in each subject by reporter, and then averaged across reporters in order to generate a straightforward continuous measure most directly analogous to grade point average. Possible scores thus ranged from 0 to 4. In a random sample, the correlation between this composite and available actual grade reports from school records for the data in Johnson, McGue, and Iacono (2006) was .89. Means, standard deviations, and effect sizes of differences for girls and boys and biological and adoptive siblings are shown in Table 2. Girls had higher grades than boys by about one-half standard deviation. Biological siblings had higher grades than adoptive siblings by about .14 standard deviation.

IQ—The siblings were assessed using an abbreviated version of the WISC-R (WISC in the following) for siblings under age 16 and using the analogous abbreviated version of the WAIS for those age 16 or older. The abbreviated versions of these tests consist of 2 verbal (Vocabulary and Information) and 2 performance (Block Design and Picture Arrangement) subtests. These subtests were selected for their high correlation (.90) with total IQ based on all subtests. Table 2 shows that boys had higher IQ's than did girls, by about one-third standard deviation. There was no significant difference between the IQ's of adoptive and biological siblings.

Parenting practices—Parents and siblings completed the Parental Environment Questionnaire (PEQ; Elkins, McGue, & Iacono, 1997), a 42-item, factor-analytically derived inventory designed to assess the relationship of each parent-child dyad in the family. The inventory includes 5 scales: Parental Involvement (e.g., "My parent tries to keep up with how well I do in school."), Parent's Regard for Child (e.g., "My parent does not seem to think highly of me [reversed]."), Child's Regard for Parent (e.g., "I often get good advice from my parent."), Conflict (e.g., "My parent and I often get into arguments."), and Structure (e.g., "My parent makes it clear what she or he wants me to do or not to do."). The PEQ was completed by each sibling about his/her own relationship with each parent. In principal component analyses, the five PEQ scales have a single dominant component that reflects primarily absence of conflict and warm mutual regard. As did Walden, et al. (2004) for MTFs, we used a composite across parents of the first principal component scores from the sibling reports as our measure of parenting practices. These scores ranged from -3.75 to 1.55. The scores decreased moderately with age, and were associated with school grades as well. Age, however, did not moderate the association between parenting and grades. Again, Table 2 shows descriptive statistics. Girls reported slightly more positive relationships with parents than did boys, by about .14 standard

deviation, primarily because girls perceived greater involvement with their mothers than did boys. Biological siblings reported more positive relationships with parents than did adoptive siblings, primarily because of greater conflict with parents in adoptive families.

Parental expectations of educational attainment (PEEA)—As part of a larger questionnaire, one parent (usually the mother) completed a single item indicating expected eventual educational attainment for each sibling. Options included 1) not completing high school, 2) high school only, 3) high school plus some trade school, 4) some college, 5) complete college, and 6) college plus professional degree. As Table 2 shows, parental expectations for overall educational attainment were high, with most parents expecting their offspring to attend at least some college. Still, parents had higher expectations for girls than for boys, by about one-third standard deviation. There was no significant difference in expectations for biological and adoptive siblings. PEEA also did not vary with age, though it is of course possible that individual parents had had different educational expectations for their offspring when they were younger than they did at time of measurement. Moreover, though PEEA was related to school grades, this association did not vary with the ages of the participants.

Engagement in school—As in Johnson et al. (2006) using MTFS, we assessed child engagement in school using questions from a self-report questionnaire on school behaviors. Items included interest in school work, studying without being reminded, turning in homework, enjoying attending school, and wanting good grades, rated on a 4-point scale ranging from “1. definitely true of me” to “4. definitely false of me.” We scored these items so that high scores reflected high Engagement and summed them. Possible scores ranged from 4 to 20. Estimated internal consistency reliabilities for the scale was .74. As shown in Table 2, girls had higher Engagement in school than did boys, by about one-half standard deviation. There was no significant difference in Engagement between adoptive and biological siblings.

Analytical Approach

The standard quantitative genetic model for a single trait is based on the assumption that the observed variance (V_p) in the trait of interest is a linear additive function of genetic (A) and shared (C) and non-shared (E) environmental variance, respectively. Symbolically, this can be expressed as,

$$V_p = A + C + E.$$

Under this model, the variance components are assumed to be independent of each other. In a sample of adoptive and biological families, there is genetically influenced variance only for the biological sibling pairs, and the extent of their genetic relationship is .5. Thus, the observed covariance for siblings in biological families can be expressed symbolically as,

$$\text{Cov}_{\text{bio}} = .5 * A + C,$$

and that for siblings in adoptive families can be expressed as,

$$\text{Cov}_{\text{ad}} = C.$$

The shared environmental variance represents experiential factors common to the members of a sibling pair that operate to make them similar. These factors may include experiences such as growing up with the same religious traditions and parental socioeconomic status. Non-shared environmental variance represents those experiential factors unique to each member of a sibling pair that operate to make them different. Such experiences may include having different teachers and friends, participating in different leisure activities such as sports, and receiving different parental treatment. The distinction between shared and non-shared experiences is

subtle. For example, siblings may experience the same event (e.g., a household move), but that event is only a shared environmental experience to the extent that it acts to make the siblings similar – they may react to it very differently. The non-shared environmental component also includes variance attributable to measurement error.

While understanding how genetic and environmental influences come together to influence any single trait is important, we are most interested in understanding how IQ, Parenting, PEEA, and Engagement come together to influence school grades, which means considering the genetic and environmental influences on these traits in a multivariate context. The standard model for a single trait can be extended to such multivariate situations by modeling the covariance between one sibling's score on one variable and the other sibling's score on another variable in a manner directly analogous to the case for a single trait. To do this, we made use of a Cholesky model implemented in the structural modeling program Mx (Neale, Boker, Xie, & Maes, 1999). This model decomposes the covariances between pairs of variables into genetic and shared and non-shared environmental components, providing estimates of the proportions of variance attributable to each component and of the associations between components for each variable. The model imposes no underlying structure on the genetic and environmental influences, and simply recounts the extent of their interrelationships. The first latent factor of each type (genetic or shared or non-shared environmental) will load on all the observed variables, the second on all the variables except the first, the third on all the variables except the first 2, and so on. The order of the observed variables is arbitrary, and the measurements of the covariances, correlations, and proportions of variance would be the same no matter what order was used. It is customary, however, to order the observed variables so that predictor variables are placed in the order of their anticipated importance to the outcome, and the outcome variable is placed last so that the path coefficients from the latent variance components to the observed outcome variable define their unique influences on the outcome variable. Thus, for this study, we placed the observed variables in the order IQ, Parenting, PEEA, Engagement, and Grades.

Figure 1 diagrams the model. The diagram shows the genetic, shared, and nonshared environmental paths influencing each of the contributing variables, with Grades at the end in order to focus the presentation on the outcome variable. The latent genetic and environmental influences are labeled with subscripts 1–5 to emphasize that these influences are not specific to the contributing variables. When the associations between genetically influenced components of variance are substantial, there is evidence that genetic effects on one variable also contribute to genetic effects on the other, and similar statements can be made for shared and non-shared environmental associations. We examined these associations in two ways. First, we looked at genetic and environmental correlations, which reflect the extent to which influences on a given pair of traits arise from common genetic or environmental sources. These correlations range from –1 to 1 and can be considered to account for common variance in the manner usual to correlations. Using the paths shown in Figure 1, the genetic correlation

between, for example, Parenting and Grades can be calculated as $a_{2Gr} / \sqrt{a_{2Gr}^2 + a_{5Gr}^2}$ (where the subscripts refer to the starting and ending points of the path), and the two environmental correlations can be calculated in an analogous manner. Second, we examined the proportions of the observed correlations that can be attributed to genetic and environmental influences common to the two variables. These proportions are sometimes called bivariate genetic and environmental influences. Using the paths shown in Figure 1, the bivariate genetic influences on the observed correlation between, for example, PEEA and Grades can be calculated as $a_{3PEEA}a_{3Gr} / (a_{3PEEA}a_{3Gr} + c_{3PEEA}c_{3Gr} + e_{3PEEA}e_{3Gr})$.

The magnitudes of genetic and environmental correlations between two traits do not depend on either their observable phenotypic correlations or on the proportions of genetic and

environmental influences on the two traits. That is, the genetic and environmental correlations may be great or small whether the observed correlations are great or small, and they can also be great or small regardless of the relative magnitudes of genetic and environmental influences. At the same time, when observed correlations are high, either or both genetic and environmental influences must draw them together, so at least one of the underlying genetic and environmental correlations will be high. The reverse is true when observed correlations are low: at least one of the underlying genetic and environmental correlations will be low. The magnitudes of bivariate genetic and environmental influences on two traits are similarly independent of both the observed correlations and relative magnitudes of genetic and environmental influences on the two traits. Bivariate genetic and environmental influences differ from genetic and environmental correlations, however, in that there is an inverse relation between bivariate genetic and environmental influences on a trait because their total will sum to 1.00, but no such relation exists between genetic and environmental correlations. The magnitude of observed correlation, however, says nothing about the likely levels of bivariate genetic and environmental influences. This means that many different combinations of associations among genetic and environmental influences may exist in multivariate situations, even when observed correlations are similar. Thus examination of the specific combinations in any given multivariate situation can be valuable in understanding the how the associations among the variables arise.

To compare results for girls and boys, we made use of the opposite-gender sibling pairs to estimate sex-limitation, or the extent to which genetic and/or environmental influences differ for females and males. Sex-limitation comes in two basic forms. When sex-limitation is scalar, differences in the influences on the traits in females and males are purely quantitative; the same influences affect both genders, but their magnitudes differ. In contrast, when sex-limitation is non-scalar, there are qualitative differences in the influences on the two genders. That is, there are influences on one gender that do not affect the other. Neale, Roysamb, and Jacobson (2006) have discussed various models that can be used to estimate the two kinds of sex-limitation, as well as the fact that, in some of these models, parameter estimates can differ depending on the ordering of the variables in Cholesky models. For our analysis, we varied the standard Cholesky model to allow for the possibility of non-scalar sex-limitation in the form of specific genetic and environmental influences on females. As Neale, Roysamb, and Jacobson (2006) noted, use of this model retains the Cholesky property that the parameter estimates are invariant with the ordering of the variables.

Neale, Roysamb, and Jacobson (2006) also pointed out that this model is not suitable as a saturated model because it does not explicitly test for the existence of solely scalar sex-limitation: it is not completely saturated. To address this, we separately estimated a fully saturated model that allowed for different magnitudes of genetic and environmental influences on girls and boys. We thus estimated models that allowed us to test for the existence of both scalar and non-scalar sex-limitation. In addition, we estimated a model that allowed for variance differences between girls and boys, and between adoptive and biological siblings.

We adjusted the Grades, Engagement, and Parenting variables for the effects of age and age². Age effects were not significant for the other variables. We thus removed the effects of age from the analysis. Because some participants were missing data for some variables, we read the raw data into the Mx program, using maximum likelihood estimation to estimate the model parameters allowing for the absence of small amounts of data. This method relies on the assumptions that the variables are reasonably normally distributed and that the data not present are missing at random (Little & Rubin, 1987). These assumptions were reasonable for these variables. No data were missing for gender. We made no adjustment for the possibility that the pattern of covariances in adoptive sibling pairs in which one member of the pair was the biological offspring of the parents differed from the pattern in adoptive sibling pairs in

which both were adopted as comparison of the sibling correlations in the two groups indicated no apparent pattern or significant differences.

Results

Descriptive statistics

Table 3 shows the zero-order correlations of the variables we used with Grades, separately for adoptive and biological siblings and for girls and boys. For comparison, we also show the correlations with IQ because IQ is generally relatively stable over time, even in childhood, and consistently shows substantial genetic influence (Bouchard & McGue, 1981). The correlations of the study variables with Grades were higher than those with IQ. The higher correlations of the variables with Grades than with IQ indicate closer links between these variables and Grades, but they say little about the directions or etiologies of these links. With one exception, the correlations were higher in biological than in adoptive offspring, but overall the patterns of correlations were similar in the two types of offspring. The one variable that was more highly correlated with Grades and IQ in adoptive than in biological siblings was PEEA. For example, the largest difference in correlations was in the correlation between PEEA and IQ in biological (.24) and adoptive (.40) siblings. This difference was significant ($p < .05$, without correction for potential multiple tests). The patterns of correlations were similar for girls and boys as well, though correlations of the study variables with both Grades and IQ were higher in boys than in girls.

Sibling pair correlations for biological and adoptive siblings are given in Table 4. These correlations provide background information about the likely presence of genetic and environmental influences on each variable as a preliminary indication of the likely results from the multivariate Cholesky model. If there were shared environmental influences but no genetic influences on the system of variables involving Grades, we would expect that the phenotypic correlations in Table 3 would be the same in adoptive and biological sibling pairs. We would also expect that the sibling correlations for these variables in Table 4 would be the same in adoptive and biological sibling pairs (though of course we would not expect the correlations in Table 3 and Table 4 to be the same). In contrast, if genetic influences were complete and there were no common shared environmental influences, we would expect that the phenotypic correlations in Table 3 would reflect half their underlying common genetic influences in biological sibling pairs (because full biological siblings share half their segregating genes) and the correlations would be 0 in adoptive sibling pairs. Thus the correlations in biological sibling pairs would be higher than those in adoptive sibling pairs. In this situation, we would also expect the sibling correlations in Table 4 to be .5 in biological siblings and 0 in adoptive siblings. There was thus evidence for both genetic and shared environmental influences in the tables. The statistical significance of the adoptive sibling correlations for the full sample indicated small but potentially important shared environmental influences (12–18%) on all the variables with the exception of Engagement. The presence of genetic influences was indicated by the greater correlations for biological than for adoptive siblings, with twice the difference between them estimating the proportion of genetic influence (34–52%). The correlations for same-gender sibling pairs were somewhat higher than those for all pairs, suggesting possible gender differences in the influences on the variables.

Because ethnicity was confounded with adoption status in the sample, we examined the variables for effects of ethnicity. There were no significant mean differences between Caucasians and those of other ethnicities with the exception of PEEA, for which the children of other ethnicities had higher PEEA by about .2 standard deviations. This appeared to be the result of their families' higher SES, as nearly all were from adoptive families.

Estimates from the Cholesky model

The indicated proportions of variance in the observed variables attributable to genetic and shared and non-shared environmental influences resulting from the Cholesky model are shown in Table 5. The Cholesky model with genders estimated separately fit well ($\chi^2 = 112.6$ to saturated variance-covariance model, with 90 df, $p = .054$; $\chi^2 = 63.8$, with 75 df, $p = .859$ to scalar sex-limitation model), and we were able to constrain the parameters equal across genders without significant loss of fit ($\chi^2 = 147.68$, with 135 df, $p = .215$ from the saturated model to the model constrained across gender). Thus the proportions shown in Table 5 are taken from this constrained model. This meant that we were not able to identify either scalar or non-scalar sex-limitation, or gender differences in the genetic and environmental associations among the variables that might help to explain the gender difference in school performance, which was our fourth research question. Given the larger sibling correlations in same-sex pairs than in all pairs, the most likely reason for this is lack of statistical power.

All of the variables showed substantial genetic influence (37–62%). In particular, genetic influences on Parenting and PEEA, which were the subjects of our first two research questions, were in excess of 60%. Shared environmental influences were small but significant (8–17%). Non-shared environmental influences made up the balances, ranging from 25–55%. These estimates were generally consistent with those from MTFS (Johnson et al., 2005, 2006) where available, allowing for the use of latent variables in those studies. They were also generally consistent with those of other researchers, where available (e.g., Bartels, et al., 2002; Bouchard & McGue, 1981; Perusse, et al., 1994). For several variables, the estimates of genetic and shared environmental influences did differ somewhat from the preliminary indications that could be derived from Table 4. Results from the formal Cholesky model we used will generally differ somewhat from the sibling correlations for two reasons. First, the formal model effectively weights the various kinds of sibling correlations by sample size, and, second, the formal model estimates parameters by minimizing the residuals across the range of variables considered, thus smoothing parameters that might result from unusual values for particular correlations in particular groups within the full sample. In general the parameter estimates from formal multivariate models such as the one we used are considered more accurate than those from examination of sibling correlations or even from formal univariate models (Neale, personal communication, January 15, 2003).

Table 6 shows the genetic and shared and non-shared environmental correlations and their 95% confidence intervals. There were significant and important genetic correlations in excess of .5 between IQ and PEEA and IQ and Grades, between Parenting and Engagement and Engagement and Grades, and between PEEA and Grades. Thus, as anticipated with our first two research questions, there were common genetic influences on Parenting, Engagement, and school performance, and on PEEA, IQ, and school performance. There were significant and important shared environmental correlations in excess of .5 between Parenting and PEEA and Engagement and Grades; in fact, all the shared environmental correlations involving Grades were significant. There were significant and important non-shared environmental correlations in excess of .5 between PEEA and Engagement and between Engagement and Grades. Interestingly, the nonshared environmental correlation between IQ and Parenting was significantly and substantially negative (–.51). There were no common genetic influences on Engagement and IQ, though there were common shared environmental influences on the two, addressing our third research question about their relative independence.

The bivariate genetic and shared and non-shared environmental influences are shown in Table 7, along with the observed phenotypic correlations for the whole sample combined. Most of the observed phenotypic correlations between these pairs of variables would generally be considered moderate. In spite of the fact that the observed correlation between IQ and Parenting was not significant (.08), the proportion of this correlation attributable to genetic influence

was .65. On the other hand, the modest but significant observed correlation between Engagement and IQ (.15) was primarily under non-shared environmental influence (.61). Most of the observed associations between the variables were substantially genetically mediated, with more than 75% of the links between IQ and PEEA, Engagement and Parenting, Parenting and PEEA, and Parenting and Grades being genetically influenced. This provides a complementary perspective to the results shown in Table 6.

Discussion

In this study, we used a sample of biological and adoptive families to investigate several propositions about the ways in which child IQ, parenting practices, PEEA, and child engagement are associated with school performance. These propositions pitted the process of coevolution as an explanation for parental influences on offspring school performance against the more common conception of parental influences as purely environmental in nature. Our results provided substantial evidence for the process of coevolution, as well as some evidence that parenting practices have relatively small but direct environmental effects. In addition, our findings suggested that offspring characteristics had more influence on PEEA than did PEEA on offspring engagement or performance. We found no evidence for gender differences in these associations. We thus infer that the mean differences in school performance commonly observed do not arise as a result of differences in the patterns of association we explored here.

Limitations of this study

This study is subject to several methodological limitations that should be considered before discussing the results in greater detail. First, our assessment of school performance is based on child's, parents', and teachers' reports rather than direct observation or actual report cards of grades from a consistently administered system. Still, a random sample of report cards correlated .89 with grade reports similarly tabulated in another sample. Second, Asian vs. Caucasian ethnicity is largely confounded with adoptive vs. biological family status in our sample. The available evidence, however, suggests that ethnicity is not associated with the variables included in this study. Third, the same reporter (the child) provided the data on parenting practices and engagement in school, and contributed to the grade reports. Fourth, much of the existing research on parental influences on academic achievement is based on use of Baumrind's (1973) distinctions among authoritative, authoritarian, and permissive parenting, and our measure of parenting practices does not lend itself readily to these distinctions. This is not a limitation of our findings, but it does make interpretation of our results in light of previous results based on Baumrind's measures less than straightforward.

In addition, our sample of families, especially the adoptive families, is generally of relatively high socioeconomic status (SES). This reflects economic advantage, as well as the educational advantage of the mothers that we noted in our description of the sample in the Methods section of the paper. The resulting restriction of environmental range may result in the understatement of shared environmental influences (Stoolmiller, 1999; Taylor, 2004). Such understatement only takes place when the variable of interest is associated with the variable on which environmental range is restricted (Taylor, 2004), but there is evidence for such an association between SES and academic achievement (White, 1982). We cannot use SIBS to measure these associations, of course, because the restriction of range in SES will also act to attenuate the correlations. We can, however, use MTFS to measure both the extent to which SES was restricted in SIBS and the disattenuated correlations among the variables. MTFS is relevant because it was generally representative of the Minnesota population from which the SIBS sample was drawn (Holdcraft & Iacono, 2002). The same arguments apply to the effects of parental education.

In MTFS, the average Hollingshead occupational level was 3.2 (between semi-professional and clerical/technical), with a standard deviation of 1.6 Hollingshead levels. In SIBS, the average occupational level was 2.5, with a standard deviation of 1.4, so the range in SIBS was somewhat restricted. The correlations between SES and grades, IQ, and engagement in MTFS were, however, rather small: .29, .23, and .17 respectively. The corresponding correlations in SIBS were .10, .07, and .07, and correlations with parental education were highly similar. The smaller correlations in SIBS reflect the restriction of range in SES in SIBS relative to MTFS. These data suggest that only about 50% of the population range of SES is present in SIBS. Stoolmiller (1998, 1999) applied all the effects of restriction in range to the shared environmental variance, but the genetic variance will also tend to be restricted to the extent that the genetic influences on SES are common to those on the variables of interest, so Stoolmiller's approach should provide an upper bound on the effect of restriction in range. Following Stoolmiller's (1999) approach, the estimates of shared environmental influence shown above would appear to be understated by about 15%. That is, the 17% of variance attributable to shared environmental influence shown in Table 5 for Grades is more likely to be about 20% in the population. This is potentially important, but it does little to alter the overall impression left by the findings we have presented. The extensive restriction of range in the sample has a relatively small effect because SES is not closely linked to Grades, nor to the other variables of interest here.

Finally, the methods we used to estimate proportions of genetic and environmental influences are based on the assumption that genetic and environmental influences are independent. The independence assumption implies that there are no genetically influenced differences in sensitivity to the environment, commonly known as gene-environment interactions. For example, some adolescents with particular genetic backgrounds may be more sensitive to abusive parental relationships than others, producing disruptions in engagement in school that affect school performance. The independence assumption also implies that there are no genetically influenced differences in exposure to the environment, commonly known as gene-environment correlations. For example, biological offspring of parents who have done well in school may inherit genes that will influence them also to do well in school, and at the same time grow up in home environments in which good school performance is particularly rewarded and encouraged. To the extent they exist, gene-environment interactions and correlations act to create differing degrees of genetic and environmental influences within different subgroups of the sample. Violations of this assumption do not, however, invalidate the overall approach. Rather, they render the estimates applicable only on an overall, average population-level basis, and they introduce systematic distortions in the estimates.

These distortions have different effects, depending on the nature of the interaction or correlation. Specifically, interaction between genetic and shared environmental influences acts to increase the estimate of the proportion of variance attributable to genetic influence; interaction between genetic and nonshared environmental influences acts to increase the estimate of the proportion of variance attributable to nonshared environmental influence. Correlation between genetic and shared environmental influences acts to increase the proportion of shared environmental influence; correlation between genetic and nonshared environmental influences acts to increase the proportion of genetic influence (Purcell, 2002). Thus the nature of the distortions created depends on the kinds of interplay involved but not modeled.

Gene-environment interactions and correlations are by their very definition multivariate in nature. Because the modeling involved in estimating them is very specific to the nature of the interplay involved, the first step in addressing the possibility of their existence is exactly the one we followed in this study: rather than estimating proportions of genetic and environmental influences on individual variables taken one at a time, we estimated these proportions in the

context of a group of relevant variables. In so doing, we treated all the remaining variables as environments surrounding each individual variable, estimating the extent to which there were overlapping influences. The variables showing strong genetic correlations and/or high bivariate genetic influences are prime candidates for exploring gene-environment interaction and correlation in subsequent research.

Evidence consistent with the involvement of coevolution in school performance

We proposed that school performance may be influenced by coevolution, or transactions between biological and cultural inheritance factors that result in transmission of culturally influenced behaviors and attitudes from one generation to the next. We proposed that these behaviors and attitudes could be transmitted through both genetically influenced adaptive learning processes on the part of offspring and genetically influenced parental teaching of adaptive practices based on their own experiences with cultural adaptation (Perusse, 1994). To support these proposals, we suggested that we should be able to observe genetic influences on parenting practices and expectations, and that these genetic influences should be largely overlapping with genetic influences on offspring engagement and school performance. We estimated that 62% of the variance in parenting practices and 61% of the variance in PEEA was under genetic influence. The genetic influences on parenting and engagement were highly correlated (.75 from Table 6). In addition, 91% of the observed correlation of .43 between the two was genetically mediated (Table 7). Results for the relation between parenting practices and school performance also provided evidence for common genetic influences: though the genetic correlation was only .29, 92% of the observed correlation between the two of .32 was genetically mediated. For PEEA, the relative strength of the relations with engagement and school performance was reversed. The genetic influences on PEEA and school performance were highly correlated (.61 from Table 6), and 53% of the observed correlation of .53 between the two was genetically mediated. The genetic correlation between PEEA and engagement was not significant at .19, and only 50% of the observed correlation of .33 was genetically mediated.

The evidence for the presence of these genetic links suggests that parents' greatest influence on their offspring's school performance arises from the genes they share with their offspring that influence the process of adapting to the school environment. This would include genes for academic ability as reflected by IQ as well as genes for engagement and, though not measured here, genes for appropriate school behavior. Because the genetic links between parenting and engagement were strongest, it would appear that it is through their influences on engagement that the genetic influences exert their effects on performance, though these links may also reflect cooperative behavior on the parts of both parents and offspring. To the extent that the links reflect parental influences on engagement, it is possible that offspring inherit general learning processes that help them to adapt in the manner best suited to their individual constellation of characteristics to the environment in which they find themselves, which in our mainstream culture includes school. One possibility that would explain this is that there are genetic influences on the behaviors and attitudes parents develop in their own experience of adapting to the school environment and use to influence their offspring's process of adaptation. This does not mean that the genetic influences determine level of school performance. Rather, it suggests that there will be individual differences in the optimal patterns of adaptation to a relatively uniform school environment. If one educational goal is for all students to attain at least some minimal level of academic performance, our findings imply that it may be necessary to do more to tailor the school environment more closely to the individual in order to realize this goal. This is probably even more important if another goal is to maximize each individual's level of academic performance.

Because the genetic links between PEEA and school performance were strongest, it would appear that the genetic influences on PEEA exert their effects directly on performance. This

is consistent with the proposal that parents take into consideration genetically influenced characteristics of the child including intelligence (80% of the observed correlation of .35 was genetically mediated, Table 7) and actual school performance in developing their expectations. We did observe small but significant shared environmental influence (14% from Table 5) on PEEA as well, providing evidence in support of direct effects of parental expectations on offspring performance. The significant shared environmental correlation of .52 (Table 6) between parenting and PEEA could also be interpreted as evidence that parental ideas about shaping offspring school performance are important in the development of their more general parenting practices, as could all of the significant shared environmental correlations involving Grades, suggesting the existence of family cultures surrounding school performance. Even the few significant nonshared environmental correlations ($-.51$ between intelligence and parenting, $.57$ between PEEA and engagement, and $.51$ between engagement and school performance, Table 6) could be interpreted as parents tailoring their school-related parenting efforts to the individual characteristics of their offspring. Together, these findings paint a very human picture of the way in which parents deal with their offspring's school performance, suggesting that they have a priori goals (likely based on their own experience with school) that help to organize their parenting practices, but that they modify these goals and practices based on the actual characteristics of the child. They also suggest that parental goals and practices do matter over and above the characteristics of the child, to at least a small degree.

Evidence involving the role of engagement in school performance

Our findings also provided important data regarding the relations between engagement and intelligence and parenting practices and expectations. First, the observed correlation between intelligence and engagement was low (.15 from Table 7), and the absence of substantial genetic or shared environmental links between the two was striking – 61% of the observed correlation was attributed to non-shared environmental influence. This is consistent with results from MTFs (Johnson, et al., 2006). The absence of links between intelligence and engagement is important because it provides evidence that interventions intended to maximize engagement in school should affect school performance, independent of student intelligence. This does not mean, however, that the same programs will increase engagement for all students.

Second, we observed small but significant shared environmental influences on parenting practices and expectations (.12 and .14 respectively from Table 5), but shared environmental influences on engagement were smaller still (.08). In addition, in spite of moderate observed correlations between engagement and parenting practices and expectations (.43 and .33 respectively from Table 7), we found no evidence that these correlations were substantially mediated by common shared environmental influences. Along with the evidence for genetic influences on engagement (.37 from Table 5), these findings call into question the assumption that parents provide primarily environmental influences on offspring engagement. They do nothing, however, to address the assumption that another major influence on engagement is the experience of competence in the school environment (Eccles & Harold, 1996; Eccles et al., 1999).

Conclusion and practical implications

In conclusion, this study provides potentially powerful insight into the manner in which the transactions between genetic and environmental influences on school performance are transmitted from parents to offspring. The findings have important implications for future research in this area because they highlight the importance of understanding how individual differences in a constellation of variables contribute to an outcome with important broad social implications (Bronfenbrenner, McClelland, Wethington, Moen, & Ceci, 1996). They also indicate that the genetic links among these variables are strong and operate in consistent ways

that have effects across the range of relevant variables. This makes clear that the use of genetically informative samples in research in this area is critical.

What are the practical implications for educational and pedagogical practices if the overall coevolutionary perspective taken in this paper is accurate? The existence of more and less academically successful ways of adapting to the school environment that are selectively transmitted both genetically and environmentally from parents to offspring suggests that, for some, school performance in youth is critical to their successful adaptation later in life, while for others, school performance in youth is largely irrelevant. Successful adaptation here is measured not by professional or economic success, but in the ultimate adaptive sense of ability successfully to reproduce. Given the importance of education to successful economic adaptation in modern western society, the pedagogical task is to improve engagement in school across all levels of ability and family background, even if this involves different pedagogical approaches for different students.

Acknowledgements

This research was supported by US Public Health Service Grants #AA11186 and MH66140 to Matt McGue and William G. Iacono. Wendy Johnson was also supported by a University of Minnesota doctoral dissertation fellowship. We thank the siblings and their families and the recruiting, interviewing, data management, and lab staffs of the Sibling Interaction and Behavior Study.

References

- American Association of University Women. Gender Gaps. New York: Marlowe; 1996.
- Anastasi, A.; Urbina, S. Psychological Testing. 7. Upper Saddle River, NJ: Prentice-Hall; 1997.
- Aoki K. A stochastic model of gene-culture coevolution suggested by the 'culture historical hypothesis' for the evolution of adult lactose absorption in humans. *Proceedings of the National Academy of Sciences, USA* 1986;83:2929–2933.
- Aspinwall LG, Taylor SE. Modeling cognitive adaptation: A longitudinal investigation of the impact of individual differences and coping on college adjustment and performance. *Journal of Personality and Social Psychology* 1992;63:989–1003. [PubMed: 1460565]
- Bartels M, Rietveld MJH, Baal GCMV, Boomsma DI. Heritability of educational achievement in 12-year-olds and the overlap with cognitive ability. *Twin Research* 2002;5(6):544–553. [PubMed: 12573186]
- Baumrind, D. The development of instrumental competence through socialization. In: Pick, A., editor. *Minnesota Symposium on Child Psychology*. 7. Minneapolis, MN: University of Minnesota Press; 1973.
- Baumrind, D. Effective parenting during the early adolescent transition. In: Cowan, PA.; Hetherington, EM., editors. *Family Transitions*. Hillsdale, NJ: Erlbaum; 1991. p. 111-164.
- Behrman JR, Pollak RA, Taubman P. Family resources, family size, and access to financing for college education. *Journal of Political Economy* 1995;97:398–419.
- Betzig, L.; Borgerhoff Mulder, M.; Turke, P., editors. *Human Reproductive Behavior: A Darwinian Perspective*. Cambridge, MA: Cambridge University Press; 1988.
- Bouchard, TJ. Twins reared apart and together: What they tell us about human diversity. In: Fox, SW., editor. *Individuality and Determinism*. New York: Plenum; 1984.
- Bouchard TJ, McGue M. Familial studies of intelligence: A review. *Science* 1981;212:1055–1059. [PubMed: 7195071]
- Bouchard TJ, McGue M, Lykken DT, Tellegen A. Intrinsic and extrinsic religiousness: Genetic and environmental influences and personality correlates. *Twin Research* 1999;2:88–98. [PubMed: 10480743]
- Bouchard, TJ.; Segal, NL.; Tellegen, A.; Keyes, M.; Krueger, RF. Genetic influence on social attitudes: Another challenge to psychology from behavior genetics. In: DiLalla, DL., editor. *Behavior Genetic*

Principles: Development, Personality, and Psychopathology. Washington, D. C: American Psychological Association; 2003.

Bradley, RH. The HOME Inventory: Review and reflections. In: Reese, HW., editor. *Advances in Child Development and Behavior*. 25. San Diego, CA: Academic Press; 1994. p. 241-288.

Bronfenbrenner, U.; McClelland, P.; Wethington, E.; Moen, P.; Ceci, SJ. *The State of Americans*. New York: Free Press; 1996.

Cavalli-Sforza, LL.; Feldman, MW. *Cultural Transmission and Evolution: A Quantitative Approach*. Princeton, NJ: Princeton University Press; 1981.

Ceci SJ, Williams WM. Schooling, intelligence, and income. *American Psychologist* 1997;52(10):1051–1058.

Chagnon, NA.; Irons, W., editors. *Evolutionary Biology and Human Social Behavior: An Anthropological Perspective*. North Scituate: Duxbury Press; 1979.

de Jong PF, Leseman PPM. Lasting effects of home literacy on reading achievement in school. *Journal of School Psychology* 2001;39:389–414.

Durham, WH. Toward a coevolutionary theory of human biology and culture. In: Chagnon, NA.; Irons, W., editors. *Evolutionary Biology and Human Social Behavior: An Anthropological Perspective*. North Scituate: Duxbury Press; 1979.

Dweck, CS. Messages that motivate. In: Aronson, J., editor. *Improving Academic Achievement*. San Diego, CA: Academic Press; 2002. p. 37-60.

Eccles, JS. Sex differences in achievement patterns. In: Sonderegger, T., editor. *Nebraska Symposium on Motivation*. Lincoln, NE: University of Nebraska Press; 1984. p. 97-132.

Eccles, JS.; Harold, RD. Family involvement in children's and adolescents' schooling. In: Booth, A.; Dunn, JF., editors. *Family-school links: How do they affect educational outcomes?*. 1996. p. 3-34.

Eccles, JS.; Roeser, R.; Wigfield, A.; Freedman-Doan, C. Academic and motivational pathways through middle childhood. In: Balter, L.; Tamis-LeMonda, CS., editors. *Child Psychology: A Handbook of Contemporary Issues*. Philadelphia: Psychology Press; 1999. p. 287-317.

Elkins I, McGue M, Iacono WG. Genetic and environmental influences on parent-son relationships: Evidence for increasing genetic influence during adolescence. *Developmental Psychology* 1997;33:351–363. [PubMed: 9147842]

Fantz, RL.; Fagan, JF.; Miranda, SB. Early visual selectivity: As a function of pattern variables, previous exposure, age from birth and conception, and expected cognitive deficit. In: Cohen, B.; Salapatek, P., editors. *Infant Perception: From Sensation to Cognition*. 1. New York: Academic Press; 1975.

Forgatch MS, DeGarmo DS. Parenting through change: An effective prevention program for single mothers. *Journal of Consulting and Clinical Psychology* 1999;67:711–724. [PubMed: 10535238]

Gadeyne E, Ghesquiere P, Onghena P. Longitudinal relations between parenting and child adjustment in young children. *Journal of Clinical Child and Adolescent Psychology* 2004;33:347–358. [PubMed: 15136199]

Gagne F, St Pere F. When IQ is controlled, does motivation still predict achievement? *Intelligence* 2001;30:71–100.

Gallimore R, Goldenberg C. Analyzing cultural models and settings to connect minority achievement and school improvement research. *Educational Psychologist* 2001;36:45–56.

Ganzach Y. Parents' education, cognitive ability, educational expectations and educational attainment: Interactive effects. *British Journal of Educational Psychology* 2000;70:419–441. [PubMed: 11059120]

Glick JE, White MJ. Post-secondary school participation of immigrant and native youth: The role of familial resources and educational expectations. *Social Science Research* 2004;33:272–299.

Gottfried AE, Gottfried AW. A longitudinal study of academic intrinsic motivation in intellectually gifted children: Childhood through early adolescence. *Gifted Child Quarterly* 1996;40:179–183.

Gutman LM, McLoyd VC. Parents' management of their children's education within the home, at school, and in the community: An examination of African-American families living in poverty. *Urban Review* 2000;32:1–24.

Holdcraft LC, Iacono WG. Cohort effects on gender differences in alcohol dependence. *Addiction* 2002; (97):1025–1036. [PubMed: 12144605]

- Hyde JS, Kling KC. Women, motivation, and achievement. *Psychology of Women Quarterly* 2001;25:364–378.
- Iacono WG, Carlson SR, Taylor J, Elkins IJ, McGue M. Behavioral disinhibition and the development of substance-use disorders: Findings from the Minnesota Twin Family Study. *Development and Psychopathology* 1999;11:869–900. [PubMed: 10624730]
- Johnson W. Genetic and Environmental Influences on Behavior: Capturing All the Interplay. *Psychological Review*. 2007in press
- Johnson W, McGue M, Iacono WG. Disruptive behavior and school achievement: Genetic and environmental relationships in 11-year-olds. *Journal of Educational Psychology* 2005;97:391–405.
- Johnson W, McGue M, Iacono WG. Genetic and environmental influences on academic achievement trajectories during adolescence. *Developmental Psychology* 2006;42:514–532. [PubMed: 16756442]
- Kaplan DS, Liu RX, Kaplan HB. Influence of parents' self-feelings and expectations on children's academic achievement. *Journal of Educational Research* 2001;94:360–370.
- Kaplan DS, Liu RX, Kaplan HB. Explaining intergenerational parallelism in adverse school experiences: Mediating influence of young and middle adulthood experience. *Journal of Experimental Education* 2004;72:117–159.
- Kellaghan, T.; Sloane, K.; Alvarez, B.; Bloom, BS. *The Home Environment and School Learning*. San Francisco: Jossey-Bass; 1993.
- Kimball MM. A new perspective on women's math achievement. *Psychological Bulletin* 1989;105:198–214.
- Laland KN, Kumm J, Horn JDV, Feldman MW. A gene-culture model of human handedness. *Behavior Genetics* 1995;25(5):433–445. [PubMed: 7487840]
- Little, RJA.; Rubin, DB. *Statistical Analysis with Missing Data*. New York: Wiley; 1987.
- Lloyd J, Barenblatt L. Intrinsic intellectuality: Its relation to social class, intelligence, and achievement. *Journal of Personality and Social Psychology* 1984;46:646–654.
- Maccoby, EE.; Martin, J. Socialization in the context of the family: Parent-child interaction. In: Mussen, PH., editor. *Charmichael's Manual of Child Psychology*. New York: Wiley; 1983. p. 1-101.
- McGue M, Elkins I, Walden B, Iacono WG. Perceptions of the parent-adolescent relationship: A longitudinal investigation. *Developmental Psychology* 2005a;41:971–984. [PubMed: 16351340]
- McGue M, Keyes M, Sharma A, Elkins I, Legrand L, Johnson W, Iacono WG. The environments of adopted and non-adopted youth: Evidence on range restriction from the Sibling Interaction and Behavior Study (SIBS). *Behavior Genetics*. 2005under review
- Mau W, Lynn R. Gender differences on the Scholastic Aptitude Test, the American College Test, and college grades. *Educational Psychology* 2001;21(2):133–136.
- Neale, MC.; Boker, S.; Xie, G.; Maes, HH. *Mx: Statistical Modeling*. Richmond, VA: Medical College of Virginia, Department of Psychiatry; 1999.
- Neale MC, Roysamb E, Jacobson K. Multivariate analysis of sex limitation and GxE interaction. *Twin Research and Human Genetics* 2006;9:481–489. [PubMed: 16899154]
- Perusse D, Neale MC, Heath AC, Eaves LJ. Human parental behavior: Evidence for genetic influence and potential implication for gene-culture transmission. *Behavior Genetics* 1994;24:327–335. [PubMed: 7993310]
- Purcell S. Cariance component models for gene-environment interaction in twin analysis. *Twin Research* 2002;5:554–571. [PubMed: 12573187]
- Reynolds CA, Baker LA, Pedersen NL. Multivariate models of mixed assortment: Phenotypic assortment and social homogamy for education and fluid ability. *Behavior Genetics* 2000;30:455–476. [PubMed: 11523705]
- Ruggles, S.; Sobek, M.; Alexander, T.; Fitch, CA.; Goeken, R.; Hall, PK.; King, M.; Ronnander, C. Minneapolis, MN: University of Minnesota Population Center; 2004. Integrated Public Use Microdata Series: Version 3.0 [Machine-readable database. <http://www.ipums.org>
- Shore, BM.; Cornell, DG.; Robinson, A.; Ward, VS. *Recommended Practices in Gifted Education: A Critical Analysis*. New York: Teachers College Press; 1991.
- Steinberg L, Elmen JD, Mounts NS. Authoritative parenting, psychosocial maturity, and academic success among adolescents. *Child Development* 1989;60:1424–1436. [PubMed: 2612251]

- Steinberg L, Lamborn SD, Darling N, Mounts NS, Dornbusch SM. Over-time changes in adjustment and competence among adolescents from authoritative, authoritarian, indulgent, and neglectful families. *Child Development* 1994;65:754–770. [PubMed: 8045165]
- Stoolmiller M. Correcting estimates of shared environmental variance for range restriction in adoption studies using a truncated multivariate normal model. *Behavior Genetics* 1998;28:429–441. [PubMed: 9926612]
- Stoolmiller M. Implications of the restricted range of family environments for estimates of heritability and nonsahred environment in behavior-genetic adoption studies. *Psychological Bulletin* 1999;125:392–409. [PubMed: 10414224]
- Taylor A. The consequences of selective participation on behavioral-genetic findings: Evidence from simulated and real data. *Twin Research* 2004;7:485–504. [PubMed: 15527665]
- Vandenberg SG. Assortative mating, or who marries whom. *Behavior Genetics* 1972;2:127–157. [PubMed: 4664207]
- Walden B, McGue M, Iacono WG, Burt SA, Elkins I. Identifying the shared environmental contributions to early substance use: The respective roles of peers and parents. *Journal of Abnormal Psychology* 2004;113:440–450. [PubMed: 15311989]
- White KR. The relation between socioeconomic status and academic achievement. *Psychological Bulletin* 1982;91:461–481.

Figure 1. Basic Cholesky model. A refers to genetic, C and E to shared and nonshared environmental influences. PEEA is parental expectations for educational attainment.

Table 1

Demographic information comparing the adoptive and biological family samples and the Census 2000 population sample

Demographic Measure	Adoptive Families	Biological Families	Census 2000 Population Sample
College education of mothers (%)	60.6	43.8	39
College education of fathers (%)	63.6	44.3	47
Mid-parent education	5.4	4.8	N/A
Hollingshead socioeconomic status	2.3	2.9	N/A

Note: On the parental education scale used, 4 corresponds to some college, 5 to a technical degree, and 6 to a 4-year college degree. On the Hollingshead scale of socioeconomic status, 2 corresponds to business managers and lesser professionals such as sales managers and school teachers. 3 corresponds to administrative personnel and minor professionals such as service managers and appraisers. Lower scale values reflect higher status.

Table 2 Descriptive statistics and effect sizes of mean differences and their significance for biological and adoptive offspring and girls and boys

Measure	Biological Offspring		Adoptive Offspring		Differences	
	Mean	SD	Mean	SD		
IQ	107.8	13.2	106.3	14.0	-.11	ns
Parenting	.1	.9	-.1	1.0	-.20	.001
PEEA	4.9	.8	4.9	1.0	.01	ns
Engagement	3.2	.5	3.2	.5	.00	ns
Grades	3.3	.7	3.2	.7	-.14	.010
		Girls		Boys	Effect size	p-value
IQ	105.1	13.3	109.3	13.8	.31	<.001
Parenting	.1	1.0	-.1	.9	-.14	.025
PEEA	5.0	.8	4.7	1.0	-.33	<.001
Engagement	3.3	.4	3.1	.5	-.43	<.001
Grades	3.4	.6	3.0	.8	-.49	<.001

Note: Effect size is the mean difference divided by pooled standard deviation, stated so that boys higher is positive, and adoptive offspring higher is positive. PEEA is parental expectations of educational attainment. IQ was on the usual scale. Parenting ranged from -3.5 to 1.5, PEEA from 1 to 6, Engagement from 1.33 to 4, and Grades from .83 to 4.0.

Table 3

Correlations of grades and IQ with other study variables in adoptive and biological offspring and girls and boys

	Grades		IQ	Grades		IQ
	Adoptive offspring			Biological offspring		
1. IQ	.43		1.00	.31		1.00
2. Parenting	.28		.05	.35		.07
3. PEEA	.57		.40	.47		.24
4. Engagement	.52		.14	.58		.15
		Girls			Boys	
1. IQ	.43		1.00	.44		1.00
2. Parenting	.28		.07	.34		.08
3. PEEA	.48		.38	.53		.39
4. Engagement	.49		.14	.55		.22

Note: PEEA is parental expectations for educational attainment. Correlations in excess of about .1 are significant at $p < .01$, adjusting degrees of freedom for correlations between members of sibling pairs. Differences in correlations are significant at $p < .05$ if they differ by about .15 and at $p < .01$ if they differ by about .20, adjusting degrees of freedom for correlations between members of sibling pairs.

Table 4

Double-entered Pearson sibling pair correlations

Measure	All sibling pairs		Same gender sibling pairs	
	Biological n=208	Adoptive n=409	Biological n=130	Adoptive n=246
IQ	.32	.15	.44	.20
Parenting	.36	.12	.32	.17
PEEA	.36	.14	.45	.19
Engagement	.28	.06	.30	.10
Grades	.41	.18	.43	.23

Note: PEEA is parental expectations for educational attainment. For all adoptive pairs, correlations of about .14 or more are significant at $p < .01$; for all biological pairs, a correlation of about .20 or more is necessary for this level of significance. For the same gender pairs, correlations of about .17 and .24 for adoptive and biological sibling pairs are necessary for this level of significance. Differences in correlations for all sibling pairs are significant at $p < .05$ if the correlations differ by about .16 and at $p < .01$ if they differ by about .21. For same gender sibling pairs, the differences in correlations must be about .21 and .26 to attain the same levels of significance.

Table 5

Indicated proportions of variance in measures

Measure	A	C	E
IQ	.54 (.27,.79)	.14 (.05,.22)	.32 (.12,.57)
Parenting	.62 (.32,.91)	.12 (.02,.21)	.26 (.03,.52)
PEEA	.61 (.30,.85)	.14 (.05,.23)	.25 (.06,.52)
Engagement	.37 (.09,.63)	.08 (.04,.18)	.55 (.32,.78)
Grades	.52 (.21,.79)	.17 (.08,.26)	.31 (.09,.56)

Note: A refers to genetic, C to environmental, and E to nonshared environmental influences. The variances could be constrained equal for boys and girls. 95% confidence intervals are in parentheses. PEEA is parental expectations for educational attainment.

Table 6

Genetic, shared environmental, and nonshared environmental correlations among the variables

	Genetic			
	Parenting	PEEA	Engmnt.	Grades
IQ	.32 (.06,.58)	.73 (.51,.94)	-.03 (-.37,.30)	.51 (.26,.72)
Parenting		.19 (-.07,.43)	.75 (.52,.92)	.29 (.01,.53)
PEEA			.19 (-.18,.46)	.61 (.40,.77)
Engagement				.59 (.29,.79)
Shared environmental				
IQ	.31 (-.08,.73)	.34 (-.01,.62)	.48 (.01,1.00)	.45 (.16,.69)
Parenting		.52 (.14,.93)	.47 (-.23,.88)	.44 (.10,.76)
PEEA			.21 (-.49,.65)	.41 (.09,.62)
Engagement				.66 (.29,.99)
Nonshared environmental				
IQ	-.51 (-.95,-.09)	-.41 (-.84,.04)	.26 (-.02,.55)	.17 (-.26,.47)
Parenting		.21 (-.30,.69)	.08 (-.36,.35)	.31 (-.15,.69)
PEEA			.57 (.28,.82)	.46 (.00,.72)
Engagement				.51 (.26,.70)

Note: Because variances were constrained equal for girls and boys, these correlations were also equal for girls and boys. 95% confidence intervals are in parentheses. PEEA is parental expectations for educational attainment.

Table 7
Proportions of observed phenotypic correlations attributable to genetic and environmental influence

	1	2	3	4
Observed phenotypic correlations				
1. IQ				
2. Parenting	.08			
3. PEEA	.35	.24		
4. Engagement	.15	.43	.33	
5. Grades	.39	.32	.53	.55
Proportions genetic				
1. IQ				
2. Parenting	.65			
3. PEEA	.80	.77		
4. Engagement	.28	.91	.50	
5. Grades	.29	.92	.53	.43
Proportions shared environmental				
1. IQ				
2. Parenting	.04			
3. PEEA	.02	.08		
4. Engagement	.11	.06	.03	
5. Grades	.27	.04	.02	.03
Proportions non-shared environmental				
1. IQ				
2. Parenting	.31			
3. PEEA	.18	.15		
4. Engagement	.61	.03	.47	
5. Grades	.44	.04	.45	.54

PEEA is parental expectations for educational attainment.