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Scientific ability

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Abstract. Following an introductory definition of scientific ability, product-oriented, personality and social psychological approaches to studying scientific ability are examined with reference to competence and performance. Studies in the psychometric versus cognitive psychological paradigms are dealt with in more detail. These two research strategies complement each other excellently in describing and explaining scientific ability and achievement or expertise in the field of science and technology. Whereas psychometric studies seem to be essential for diagnostic and prognostic purposes, cognitive psychological studies help to explain excellent performance. Finally, various possibilities for nurturing scientifically gifted adolescents are discussed, with sex-related problems being touched upon.

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Generally, the hypothetical construct 'scientific ability', or 'scientific giftedness', can be defined as scientific thinking potential or as a special talent for excellence in (natural) sciences. Both descriptive and explanatory terms are necessary for a theoretically *and* practically efficient definition. This further necessitates different research strategies. Below are described a minimum of research approaches which can be distinguished.

Product-oriented approaches

Exceptional performance in the sciences is used as an indicator of special scientific ability or competence. This approach is plausible and, of course, very practical, which is why it has long been the preferred method in creativity research (Sternberg 1988, Glover et al 1989). However, it does not answer the following questions. (1) Is exceptional scientific achievement primarily determined by cognitive problem-solving competence or are other factors—motivation, for example—also important for eminent achievement? (2) Are there scientific under-achievers, that is, individuals who do not turn their potential abilities into adequate scientific performance? If there are, the use of performance indicators to assess scientific abilities will be inadequate or even misleading.

This approach is also unsatisfactory from an educational point of view—for the nurturance of scientific talents in adolescence—and also neglects social and cultural influences on the development of giftedness.

Kim (1990) suggested that the *results* of scientific research should be classified according to the following criteria with reference to the (process) characteristic 'scientific discovery'.

Alignment. This refers to the isomorphy between the model and reality, that is, the validity of theories and their universality.

Possibility. 'A good deal of the theoretical work in the sciences is also one of construction. This relates to the development of general models, frameworks, or theories that can accommodate diverse empirical observations' (Kim 1990, p 91).

Impossibility. A 'negative' result, i.e., the proof that a hypothesis does not hold true, is just as important scientifically as the confirmation of a hypothesis. Einstein's Theory of Relativity or Heisenberg's Uncertainty Principle are famous examples of this.

Trade-offs. 'An important class of results relates to interdimensional trade-offs. These may relate to the relationships between performances and efficiency, or time versus space, among others' (Kim 1990, p 92).

Whereas trade-offs and possibility are relevant evaluation criteria for *technological* products, alignment and impossibility are central considerations for the importance of *scientific* results.

Personality-oriented approaches

One can differentiate at least three paradigms here: psychometric, cognitive psychological, and neuropsychological or neurobiological approaches.

The psychometric paradigm

In the psychometric paradigm, an attempt is made to identify or measure cognitive and non-cognitive (e.g., motivational) personality traits that could be the basis of scientific ability. The following characteristics, which include both intelligence and creativity aspects, are frequently mentioned: formal–logical thought processes, abstract thinking ability, systematic and theoretical thought processes, and individual potential for creativity—problem sensitivity, inventiveness and flow of ideas, the ability to restructure problems (flexibility) and originality of solving methods and of products. In addition, non-aptitude traits, such as intellectual curiosity and searching for knowledge, exploration and the desire to question, are considered important. Other frequently mentioned characteristics include clear interests, a need to seek information, intrinsic achievement motivation, goal orientation and persistence at tasks, tolerance of ambiguity, uncertainty and complexity, and non-conformity. After childhood, these characteristics and their configuration are considered to remain relatively stable, generating differences between individuals, and so can be used in diagnostic–prognostic models for predicting exceptional scientific ability. The problems involved in this approach are discussed in Hunt (1987), Benbow & Arjmand (1990), Trost (1993) and Gardner (1993, this volume). Despite the justified criticisms of psychometric paradigms, as yet we have no better alternatives by which to predict scientific excellence, as explained below.

In their meta-analysis of 50 international studies on the ability of personality characteristics to predict scientific and technical achievement, Funke et al (1987) calculated a mean (corrected) validity coefficient of 0.38 across all predictors studied. Of all the individual types of predictor, coefficients were highest for the biographical questionnaire, followed by subject-related ability and creativity tests. General intelligence and creativity tests had the lowest prognostic value.

Trost & Sieglen (1992) studied early biographical indicators of exceptional scientific and technological professional performance in West Germany in a combined prospective–retrospective study. During 1973, more than 9000 students from the senior year of the *Gymnasium* (13th-grade students, about 19 years old) were given a general test of studying ability. In addition, school grades, teachers' evaluations and data from questionnaires about the students' study and work habits, extracurricular interests and activities, their study and professional plans were obtained, as well as demographic and sociographic information. In 1990, 17 years later, 3554 subjects from the 1973 sample were questioned retrospectively. At this point it was possible to measure professional scientific success (the number and type of publications, patents, gross income over DM180 000 p.a., direct responsibility for more than 50 employees, etc.). In order to determine the predictive function of various indicators, Trost & Sieglen (1992) determined d scores (for interval scale α values) and ω scores (for nominal and rank order data) for the effect size of differences between the subgroup with higher professional performance and the representative comparison group (Table 1). According to Cohen (1977), d scores above 0.2 and ω scores above 0.1 indicate weak effects, d scores above 0.5 and ω scores above 0.3 intermediate effects, and d scores over 0.8 and ω scores above 0.5 strong effects.

The most powerful long-range predictors of professional success in science and technology are apparently domain-specific problem-solving abilities and motivational and social leadership abilities. These results correspond well with those from other studies, e.g., Benbow & Stanley (1983), Stanley & Benbow (1986), Rahn (1986), Swiatek & Benbow (1991), Facaoaru (1992) and Subotnik & Steiner (1993). Rahn (1986) studied all of the 1123 German winners of the

TABLE 1 Values for the effect size for various predictive characteristics of differences between a group with high professional achievements in science and technology and a group with average such achievements, according to Trost & Sieglen (1992, p 102)

	Effect size	
Predictive characteristic	*d value*	*ω value*
Motivation and ability to solve problems	0.71**	
Desire to influence, initiative and leadership success	0.62**	
Search for knowledge	0.43**	
Concentration ability and persistence	0.18*	
Self-evaluation of school performance during the last three years at school	0.35**	
Results of quantitative section of the test for study abilities	0.31**	
Average grade	0.29**	
Total score in test of study abilities	0.22**	
Early home upbringing directed towards active and independent coordination of one's life	0.42**	
Nurturance by teachers	0.31**	
Mother's educational level	0.26**	
Father's educational level	0.21*	
Value placed on education within the family	0.21*	
Parental support of the development of abilities and talents	0.20*	
Number of extracurricular activities named	0.26**	
Average time spent on extracurricular interests	0.23**	
Number of subject-related interests named		0.11**
Number of prizes won in school competitions		0.08**

*$P<0.05$, **$P<0.01$.

annual competition *Jugend forscht* (youth researches) at the state and national level from 1966 to 1984. The total number of participants was 23 945, 81.9% boys and 18.1% girls. Rahn studied the course of winners' school, university, professional and general lives, and came to the conclusion that interests and individual goals, as well as achievement motivation and action competencies, are more important than intelligence factors; cognitive abilities were, however, not tested in Rahn's study. Subotnik & Steiner (1993) analysed adult manifestations of adolescent talent in science in the USA. In their longitudinal study of 1983 winners in the Westinghouse Science Talent Search, Subotnik & Steiner (see also Subotnik et al 1993) got results quite similar to those described above. See also Zuckerman (1987, 1992), who stressed the mentor–apprentice relationship as well as sex-specific differences in science.

Recent research on the expertise paradigm from a lifespan perspective has proven that the development of expertise, that is, performance at high or the highest levels, is a function of an individual's developmental stage. Whereas motivation and interest in a subject or domain seem to be the determining factors at early stages, instructional methods and quality of teachers become more and more important as the difficulty level increases (Ericsson et al 1990). Hayes (1989, p 143) also remarks that 'the origin is in motivation not cognition'. Furthermore (and partly in contrast to Hayes' statement), differences between individuals in scientific problem-solving competence depend at the novice level more on cognitive abilities, but at the expert level more on learning experiences and domain-specific knowledge. (See also Weisberg 1986.)

The role of cognitive abilities is probably underestimated in studies using the expert–novice comparison paradigm and also in educational practice, because confounding variables such as the acquisition of knowledge and intellectual abilities, and restriction of range (which reduces the relationship [correlation coefficient] between intelligence and performance; see Detterman 1993, this volume), are not considered. During the evaluation of various enrichment courses for gifted students in Baden Württemberg, we found that the instructors did not select their students according to motivation, interests and achievements, as they had claimed, but according to intelligence; there was, however, in fact a strong consideration of (domain-specific) cognitive abilities (Hany & Heller 1990). This observation was recently confirmed in a study evaluating a scholastic acceleration programme (K. A. Heller, J. Brox & B. Sacher, unpublished work 1993). C. Facaoaru (unpublished final report on the Technical Creativity project to the Federal Minister of Education and Science, Bonn, 1992 [University of Munich]) also drew similar conclusions from her evaluation of five extracurricular courses for technical creativity. She also examined various personality characteristics. Although the 11–19-year old students who participated in these extracurricular courses did so voluntarily, and intelligence test scores were not used as an admission criterion, the students demonstrated above average *domain-specific* cognitive abilities (Table 2).

TABLE 2 Means, standard deviations and minimum and maximum T-values[a] in ability tests given to 11–19-year-olds participating voluntarily in extracurricular courses for technical creativity

Ability characteristic	*Mean*	*SD*	*Min*	*Max*	*n*
AWI: spatial representation	64.54	11.17	42.00	80.00	67
APT: physical and technical comprehension	60.96	12.79	36.50	80.00	67
KFT Q-scales					
Arithmetic thought (Q1 + Q2)	61.43	12.25	35.00	80.00	28
Calculating ability (Q3 + Q4)	59.32	11.61	33.00	80.00	28

[a] $M_T = 50$, $s_T = 10$.

The cognitive psychological paradigm

Whereas psychometric theories cannot be replaced in the identification of scientifically gifted adolescents, or in the prediction of later professional or university success, they do not provide any explanatory information. In contrast, information-processing or thought process analyses in the cognitive psychological paradigm can answer questions about the conditions required for the development of scientific competence and expert performance. Examples of this include the cognitive component approach of Sternberg and colleagues (Sternberg & Davidson 1986) and the experimental diagnosis of giftedness of Klix (1983). Van der Meer's (1985) experiments on mathematical and scientific talents also exemplify this approach.

Process-oriented approaches to individual differences are directed to the identification of those psychological mechanisms that form the basis for individual differences at the level of performance of cognitive processes. According to Klix (1983), the ability to reduce complexity in problems through information processing and thus to reduce the cognitive demands for solving a problem is a characteristic essential for scientific giftedness. Task-related motivation plays a key role in this, primarily by generating and maintaining the activity level necessary for an effective search, introduction and processing of relevant information through to finding a solution (Van der Meer 1985, p 231).

In an approach similar to that used by Sternberg & Davidson (1986) in their analysis of components, Van der Meer gave subjects tasks requiring inductive and analogous thinking. Analogous conclusion processes are made up of the recognition and transfer of relationships between terms from one domain to another. Analogous terms in Van der Meer's experiments were chessboard-like patterns of varying complexity. The most important empirical finding was that mathematically/scientifically gifted adolescents (special students in mathematics at the Humboldt University in Berlin) showed above average ability to solve the analogy test items. The author viewed this as an essential feature of mathematical/scientific ability, and it can be demonstrated up to the 9th grade (15-year-old students). In addition, the mathematically talented process information in basal cognitive processes faster than average students, as well as showing less effort in finding solutions to complex tasks. It could be that they have more effective problem-solving strategies that are better adapted to the structure of the task. This means that mathematically/scientifically gifted students from the upper grades expend less effort than students of normal intelligence, and rely on minimal intermediate storage of partial results in memory, reflecting a higher quality of thinking. The superior manner in which basal operations are combined, and the increased simplicity and effectiveness of problem-solving, are, according to Van der Meer (1985, p 244), characteristic of mathematical/scientific talent. Because extraordinary interest and persistence in cognitive challenges play a role in solving difficult, complex problems, Van der Meer believes that reliable predictions of later excellent performance can be made on the basis of early high achievements in mathematics and natural sciences. One limitation on this idea is the fact that only a few aspects of scientific ability, central though they are, are measured here (see Benton & Kiewra 1987). In their monograph entitled *Scientific discovery*, Langley et al (1987) discussed another central aspect of scientific research which seems to be of general importance for generation of and decisions about hypotheses. In relation to this, Clement (1989) emphasized three different functions of analogies: (a) the heuristic function of indicating new observations or new explanatory characteristics that should be considered; (b) the role of a 'rough initial model of the target situation' that can be developed and refined later; and (c) the explanatory model which is to be linked through analogies to the target situation (p 361).

Further information about cognitive approaches in the context of creativity research can be found in Sternberg (1988, p 125–238). See also Siegler & Kotovsky (1986).

Neuropsychological and neurobiological approaches

Neuropsychological and neurobiological approaches are dealt with elsewhere in this volume, so I can limit myself to some literature citations: Obler & Fein (1988) and Eysenck & Barrett (1993); see also Plomin (1988) and Thompson & Plomin (1993).

System-oriented or environmentally oriented and social–psychological approaches

Most of the studies that follow such approaches were developed to prove that certain environments promote creative learning. Nurturant and non-nurturant socialization influences on the development of giftedness have been studied mainly in the social settings of the family, the school, in leisure time or in professional environments, e.g., Amabile (1983), Gruber & Davis (1988), Csikszentmihalyi (1988). According to these authors, not only stimulating learning environments and experimental opportunities are necessary, but information sources and community resources must also be available. Expert and 'creative' role models are particularly important. New science curricula which meet the special needs of gifted adolescents have been recognized to play a key role. Linn (1986) collected important information for a necessary revision of the science curriculum. The process of *discovery* in science learning seems to be especially appropriate for facilitating the development of competency in scientific problem-solving, together with *domain-specific knowledge* and *autonomous learning*. These principles are of general importance for the education of the gifted (cf., Zimmerman & Schunk 1989, Colangelo & Davis 1991). For a review of programmes and strategies for nurturing talent in science and technology, see Halpern (1992) and Pyryt et al (1993).

Future directions and a consideration of sex differences

Although my coverage of the various approaches has been brief, it is apparent that none of them can be ignored if one is trying to explain and describe the construct 'scientific ability'. The limitations of the individual paradigms have led to the recommendation of synthetic approaches (e.g., Gardner 1988; Sternberg & Lubart 1991). These synthetic approaches, and interdisciplinary exchange of information, should be important goals of this symposium. Other authors emphasize the role of coincidental factors or the importance of situational variables (Simonton 1988, 1991), which cannot be dealt with here in detail. I would like to summarize several considerations about the development and nurturance of talented adolescents in the field of science and technology in five points (for more details, see Heller 1992a).

(1) The interaction of scientifically talented youth with successful scientists is often recommended in the literature and seems, from experience, to be beneficial (Zuckerman 1992, Jacobi 1991). However, the role-model hypothesis cannot be proven to explain differences between the sexes in talent and performance in the areas of mathematics, science and technology (Beerman et al 1992). Independently of this, one expects that the master–pupil relationship will, as in the fine arts, have positive effects in science education. Studies at the Technical University of Dresden and at the University of Leipzig have documented this; see also Zuckerman (1992).

(2) If one compares proven stimulating institutions of higher education or research laboratories with those with little or no stimulatory effect, the following characteristics of the successful institutions become obvious: the requirement for a high degree of commitment to tasks and high demands, coupled with an open-mindedness for new ideas; and, a readiness to participate in open, critical but constructive discussions and a balance between solidarity and competition in dynamic interactions among group members (Amabile 1983, Weinert 1990).

(3) Creativity in science and technology can be seen primarily in original procedures and new methods, useful inventions and socially valuable products. The task of schools and universities is, therefore, to create an environment suitable for the acquisition of methodological and factual knowledge and abilities, and to show how these can be used in situations which are challenging to the individual. Creative variables and role models play an important role (Van Tassel-Baska & Kulieke 1987).

(4) When there is a basic consensus between the team members about research ideology, interdisciplinary or intradisciplinary research teams put together in a heterogenous fashion provide the best conditions for creative performance in the natural sciences (Weinert 1990). Such teams increase individuals' factual and methodological expertise, and offer a change in point of view which is a positive force in scientific production.

(5) Finally, one should take a look at the sex differences in scientific competence and performance, which have been receiving more attention recently. Sex differences are most evident in the hard sciences (physics, chemistry, astronomy) and in mathematics and technology. Space and quantitative factors are the areas of cognitive ability in which women and girls are usually weaker than men and boys. These effects tend to increase rather than decrease with increasing ability (Beerman et al 1992; see also, this volume, Benbow & Lubinski 1993, Stanley 1993). Inappropriate motivational patterns and causal attribution styles need to be eliminated from nurturance approaches for scientifically gifted girls, and their scientific problem-solving abilities need to be strengthened. In the early phases of intervention, the problem of eliminating deficits in prior knowledge, e.g., in the areas of physics or technology, should be given special attention. When such personality-oriented nurturance approaches are accompanied by supportive educational and classroom measures, we believe that feminine competence and performance in science and technology can be boosted, and we favour this approach over organizational alternatives or quotas (whose negative effect on the self-image of the gifted is frequently overlooked). A quasi-experimental study examining the central hypotheses of this model has been presented recently (Heller 1992b).

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DISCUSSION

Hatano: Your review was comprehensive, but you neglected one area which seems to me important, that is, the informal knowledge acquired by children in their everyday lives. You referred to the significance of analogy, but analogies need source domains, and source domains are often taken from everyday experience. Science and mathematics are different from learning a musical instrument. For science and mathematics, practice is done outside school, at least to some extent. Recent developmental theories suggest that children possess rich and fairly accurate knowledge in, for example, physics, psychology and biology. The good students in science and mathematics can use such informal knowledge more skillfully than other students.

Heller: I agree with you. Two years ago we began a study of leisure-related technical experiences of 13–15-year-olds (Heller & Hany 1991, Hany & Kommissari 1992). This is an important issue, but studies are rare. Our preliminary results suggest that youngsters, male and female, acquire subjective misconceptions in physics in their leisure time. It's not sufficient to provide adolescents with the opportunities to experience and learn—we must also ensure that the informal knowledge they acquire is correct, especially physical concepts. About 50% of boys' concepts analysed were incorrect, and 80% of the girls'.

Stanley: Camilla Benbow and I have long wondered why boys seem to learn more outside school than girls. If males are already geared more towards theoretical and investigative attitudes, it is logical that they would learn more incidentally outside school. However, if that is the case, girls should be learning more aesthetic and social things outside school. It would be interesting to test that. You could get the six evaluative attitude scores for various people and see what individuals high on each attitude know. It makes sense to suppose that in the scientific and mathematical areas the boys who are doing poorer school work than girls but getting better scores on the tests are actually learning more outside school classes.

Fowler: We should consider the origins of differences between the sexes. I taught in a nursery school while I was writing my dissertation. Being oriented already towards trying to encourage girls to participate more in the 'thing world', the mechanical–spatial construction activities in which boys are so involved and which apparently lay the foundations for science and mathematics, I ran up against two major problems. One was the fact that the teachers themselves were virtually all women, and were not interested in or cognizant of these orientations. The second problem was that the boy culture itself, particularly by the age of four, is firmly entrenched. If you try to get the girls and boys to play together with blocks or vehicles, the boys employ exclusionary tactics, and they are persistent and strong. You can do this more easily in a family. I have three daughters, and we set up a subculture combining the boy and girl worlds. I don't want to make causal inferences from such limited evidence, but all three of my daughters were strong in mathematics; two of them scored highly, 670 and 720, in SAT-Mathematical, as well as in verbal tests. The third didn't score quite so highly on the SAT-Mathematical test (570), but this may have been because she attended a bilingual school where even the mathematics was taught in French. According to the SAT manual, such experiences may depress SAT scores.

Mönks: Professor Heller said that the development of expertise is a function of the developmental stage. We have been talking about prodigies, and a prodigy is simply a person with precocious functioning. When we are talking about developmental stages, we have a kind of normative framework, an age-related framework; the developmental stage is, to a certain extent, related to age. I had thought that highly able children cannot be identified with reference to a developmental stage, because they do things earlier than developmental psychology text books tell us they should.

Ericsson: Micki Chi (1978) has done a lot of work in this area. She has studied young chess experts to see how they differ from adult experts in their knowledge structures. Young experts, even though they may be only 10 or 12, resemble adult experts of a corresponding performance level more than they do other children. They are given appropriate instruction and practice, which seems to encourage the development of more complex structures in their domain of expertise than develop naturally in other areas of everyday life.

There are strong relations, though, between age and the time at which an individual attains the highest levels of performance, such as when he or she is most likely to become world champion in chess or to break the world record in a sport. Any physical performance will obviously be constrained by size and other maturational factors. Eminent contributions to science, or the writing of classic novels, occur most frequently between the ages of 30 and 40, which may reflect the necessity for a combination of maturation and acquisition.

Mönks: Is it simply that highly gifted children are developmentally ahead of other children of the same age? Early maturation indicates age-independent development.

Ericsson: Normal development within a domain can be speeded up, but, if you take a comprehensive view, there may still be maturational factors that constrain achievement of the highest levels of performance. In music, for example, it's well known that a child may develop mechanical skills much faster than expressive skills.

Gruber: Professor Heller, what I particularly liked about your paper was that you made a real distinction between creativity and ability, or creativity and giftedness. These are two quite different concepts, two different fields of research, in which different factors are emphasized. You spoke of biographical analysis, domain-specific knowledge and motivation, all taken together as a package that in a way describes the task someone has in becoming a creative person. We were talking earlier about the need for practice. A field like natural history, where you can go out in the woods and collect insects or whatever, is one in which you can amass thousands of hours of experience as a child and as an adolescent. That was clear in Charles Darwin's case. I haven't really calculated the number of hours he accumulated, but two hours a day, day in and day out, for years and years, would not be an exorbitant guess. But, even being a natural historian like that, a collector at a high level, not just a kid messing around, didn't make a theoretical biologist of him. Darwin went hunting beetles in the woods with his pals, and they were all passionate about what they were doing, but the others did not become biologists; one became a minister, and another a judge. We need to link up the fields that we are dealing with here, which seem to be passing each other by as we talk about different things. One part of such an endeavour would be a critical examination of the nature of the task involved in becoming a creative person. I don't mean to imply that all creative people are the same—in fact, quite the opposite. To be creative in different fields requires different things, and even in one domain different things apply at different points in history. As Holmes (1989) pointed out, what Lavoisier needed to be a good chemist was quite different from what Hans Krebs needed to be a good chemist. I am not objecting to the use of testing, but it should be supplemented by a careful and considered analysis of the work involved in being creative. Starting from childhood and working forward in time is one approach. Starting with the genuine article, the creative person, and actually examining what he or she has achieved is another. This approach is not a collection of anecdotes, but careful historical and biographical research.

Heller: I tried to explain some different approaches to research in this field, but I also stressed my opinion that it is necessary to combine different approaches to solve complex problems. Let me give an example. In our research work over the last five or six years we have combined intellectual and creative factors to investigate problem-solving processes related to difficult, complex tasks. For a particularly challenging scientific problem, you at first need creative ability, for the generation of hypotheses and so on. You also need convergent thinking processes to prove these hypotheses, plus a flexible, available, domain-specific knowledge base. For many problems in life, both creativity *and* so-called intellectual competence are required.

Bouchard: I should like to make a comment on the prediction of creativity. I'm not terribly familiar with this literature, but in my experience, when people do research in the area of scientific creativity and giftedness, and they say they have measured IQ, in fact all they've done is administer a five-minute verbal ability test or an eight-minute vocabulary test. My own mentor, Donald MacKinnon, for example, didn't even bother to measure IQ in his studies of creative people because he thought it wasn't relevant. They went back years later and measured Wechsler adult inventory scale IQs for many of the participants. There's a fundamental bias against using IQ as a predictor. When you compare IQ tests or general ability tests with personality tests, you run against the problem that the personality measures, the motivation measures, are obtained concurrently rather than predictively. These people already know how they feel about what they're reporting. One wonders whether you would get the same results if you were working on a predictive basis. There's a bias towards emphasizing high correlations for these measures and it may be artifactual.

I should also like to repeat what I said earlier (p 42) about chance effects influencing outcomes. Howie Gruber brought up the example of Darwin, which is a nice example of how one can look back at the history of a case; but, again, you can be misled. It would be easy to conclude, for example, that Darwin was able to come up with the theory of evolution because he came from a wealthy family, which meant he was able to pay his way on The Beagle and had time to work with all the data he gathered. In Darwin's case, though, we have a control—Alfred Russel Wallace, who was a poor school teacher who migrated to Malaysia and had to go out and collect bird specimens and send them back to England to get paid to continue what he was doing. Wallace came up with the same theory at the same time. Unless you have built-in controls, you can be terribly misled.

Gruber: In fact, Darwin thought of it in 1838 and Wallace in 1858. This demonstrates the value of broad historical knowledge, not that you should ignore it and replace it with psychometric testing. You are perfectly right in almost everything you said about Darwin, but the way to do the work isn't to try to winnow out test-like data, but to use the biographical data, the notebooks, to reconstruct how Darwin actually did his work. I'm not trying to make a prediction about Darwin. We *know* that Darwin developed a theory of evolution. Making believe that you are predicting it by some kind of methodological legerdemain is foolish, and a waste of the opportunity to form a better picture of how creative people do their work. People should treat this as a respect-worthy analysis and then connect it up with the understanding of the abilities that go into that work, not treat one approach as kosher and the other one as tref—unclean.

Csikszentmihalyi: The advances in understanding high ability in the future will probably come if we take seriously the question of the difference between domains studied. What are the differences in adult outcomes, and how can we characterize the difference between domains? One way to describe domains is in terms of how enclosed they are, or how contextual. For example, a seven-year-old playing chess is tackling essentially the same task as a 50-year-old chess international grandmaster, not only in terms of the task itself, but also in terms of the social context. A chess tournament has the same arrangement throughout one's lifespan, and the same arrangement in different countries. Chess is a pure, self-contained domain. After chess, I would place high level mathematics or perhaps classical music; classical music is more or less the same across history, in terms of both time and culture. It's not surprising that these are the kinds of domains for which the predictions from childhood are the easiest to make. With other types of abilities the social context changes with age, and the performance expectations change, both culturally and historically, which makes prediction more difficult because the social context, the motivation and the particular ways of processing information that are required at different ages have to be taken into account. We are talking past each other because we are looking at different domains, and at different predictive tasks. I've been involved with the visual arts, where prediction is incredibly difficult because every 15 years the performance expectations change. At one point a successful artist will be one who is naturalistic, then the fashion changes to an expressionistic one or back to a geometric one, or back to pop art. Different types of young people are able to perform at high levels, depending on their motivation and skills. Perhaps you would then say we should focus on areas where we can make good predictions. If we did that, we would miss a lot of the richness about high ability. We need to have patience with the messier domains.

Sternberg: I would like to question an assumption that Julian Stanley and Camilla Benbow and perhaps others are making. Let's compare what we are talking about with what medical researchers do when they test the disease-fighting ability of various medicines. First, they try the medicine in a laboratory, out of the context of the body. If it works, they take that as a good sign and test it in the body. If it doesn't work, they may look for some other way to make it work, but if it only works in a test-tube, that is viewed as a failure. We seem to do the reverse. Instead of saying that what's really important is the disease-fighting ability in the body, we say that what really counts is what you show in isolation. We look at ability shown by tests, which after all are just a medium, like anything else is a medium, for measuring abilities. Then we find that on a lot of tests the boys do better, whereas in school the girls tend to do better. There seems to be an implicit assumption that the girls do better because they play a better social game, they behave better or they know better how to interact. The implication is that there's something shady about that, and that the boys really have more ability. If you consider my medical research analogy, you might say that the girls have more ability because they show it in context. What really matters is what you *achieve* with your abilities, not what you can do sitting for an hour in a testing centre.

Benbow: Girls show better performance in the classroom, as reflected in grades attained, but more boys earn degrees in the physical sciences. Many more boys make it through to the portals in the physical sciences, and from these they can go on to be creative. We can identify children at the age of 13 who are likely to get a PhD in a physical science. Whether the smile of good fortune, special educational opportunities, the field and the domain all come together in the right way will determine to a large extent whether the individual who has passed through all the portals will do something that will be remembered. We can't predict that. I don't understand the point you're trying to make. More boys get advanced degrees, and many more boys than girls have gone on to do great things throughout history.

Sternberg: But boys and girls throughout history have not had equal opportunities.

Benbow: You are the one who is telling me the girls are more successful. I didn't say that.

Sternberg: I'm saying that you should look in context. You use school achievement as a criterion. One could easily argue that the girls have more ability than the boys, because *in context*, they perform better. If you told me that until recent years more men than women made achievements in medicine, I would be less than impressed, because in the past women weren't admitted to medical school. It would be interesting to compare men and women actually in jobs now, male versus female psychologists, for example. Are males achieving at a much higher rate, if you control for other variables?

Benbow: Yes, they are. I agree that as doors are opened to women, things can and will change. For example, out of our first cohort of mathematically talented students, who were identified in the early 1970s, many more of the boys than the girls eventually went to medical school. Five years later, out of our second group of mathematically talented children who were at least as able as our first group, more of the girls than the boys eventually entered medical school. The difference between the sexes had been reversed.

The next question is, why aren't there as many female as male psychologists at high levels of academia? Females do not publish to the same extent as males. Within their domain, females tend to gravitate towards the teaching end of the academic role, not the scholarship and research end. Why is that? Why are these decisions being made? Females are choosing to focus their energies in different ways. You say that girls do better in terms of course grades than boys through school. That's probably true, although differences are small (Kimball 1989), but new evidence indicates that ability relates to course selections. Girls tend to enrol in college for courses in which aptitude is less strongly related to performance, and grades eventually achieved in these courses happen to be higher. In contrast, males tend to enrol in courses where aptitude relates more strongly to performance, yet course grades happen to be lower in those disciplines. The point I am trying to make is that even with an apparently simple factor such as course grades there are a lot of confounding variables that have to be accounted for before proper conclusions can be drawn. I'm suggesting that you look at your argument that girls are more successful than boys from a different perspective.

Stanley: Bob Sternberg's analogy seems to me incorrect. We don't administer psychometric tests to laboratory rats to determine whether or not the tests are applicable to humans.

Sternberg: The question is, what is the value of taking a test in a room for an hour?

Stanley: Ability testing utilizes a short but systematic and probing sample of behaviour in a carefully controlled, standardized situation meant to elicit maximum cooperation and effort.

Benbow: Ability test scores do predict future academic performance and do so well. That is the value of such tests.

Gardner: At the early levels in college science, you wouldn't be able to distinguish the women's dossiers from the men's. They have high test scores, good grades and career ambitions. However, there is a dramatic change from one year to the next. One could argue that women don't really have the aptitude, and when things get more difficult they drop out; but one could make an equally powerful, if not more powerful, sociological argument about role models, ways of studying together, and decisions between career and family. One has to be careful before assuming that the major determining factor, in some abstract sense, is that women students cannot be perfectly good scientists.

The area of psychology I know most about is developmental psychology. I would say that there's absolutely no difference in this field between the top males and females. You might say that developmental psychology, because it involves children, would interest women more, and that historically there have been fewer sanctions against women going in to that field. But I'm talking about people making contributions, people whose ideas have had real effects in the field.

Even in the current context, forgetting about the history, there are powerful signals which make it difficult for women to continue certain subjects in college. In certain fields, such as developmental psychology, where there have been fewer sanctions, there is no sex differential in scientific contributions.

Benbow: We are making the same general point, but are coming at it from different perspectives. I am suggesting that there are many more pulls on females than males which affect the types of choices they will make; gifted females are more broadly developed, with more competing interests than gifted males. Also, males in our sample of high ability students have been much more committed to a full-time career than such females, a finding that has remained stable for over 20 years. This certainly affects females' choices.

Many females go into psychology, but there are few female experimental psychologists. Even within a discipline, females, just as males do, gravitate towards those areas which better fit their preferences and needs. I don't think developmental psychology attracts women just because there are fewer sanctions. I believe part of the reason is that developmental psychology is more congruent with females' profiles of preferences and needs. Although ability is an important factor that affects your career choice, so do your preferences, commitment to family life, and many other things. More females than males are awarded PhDs in psychology, but most of the females go into clinical practice, rather than academia. It isn't that females aren't developing their talents, but that they're choosing to develop them in different areas.

You also mentioned role models. Role models are important, although I think that males can be good role models for females. But, consider the Asian Americans who are taking over science in the USA. Who were or are their role models?

Bouchard: You have just given the most powerful refutation I have ever heard of the most overplayed, non-empirically demonstrated explanation one can hear in psychology. The evidence for role models being causal factors is practically nil. Role models are repeatedly postulated as an *ad hoc* explanation.

Gardner: Do you mean gender-linked role models?

Bouchard: I mean role models as a general phenomenon.

Fowler: Would you accept the concept of mentors?

Bouchard: That's a different concept. A mentor is a person who provides a certain kind of training. The generalized notion of some kind of abstract role model is just a pseudo-explanation.

Fowler: In the history of the handful of great women mathematicians there was always some person who served as a special mentor, typically a male, because males were the ones available. These mentors were models of some sort.

Bouchard: That's a much more generalized explanation. As Camilla Benbow said, males can act as an exemplar and provide guidance. The idea of the role model most often carries with it the requirement that the model be of the same sex, race, etc.

Gardner: Nobody took that position except you!

Detterman: Zuckerman's (1967) study showed that many Nobel Laureates had studied with previous winners of Nobel Prizes.

Gardner: You would have to work with male Nobel Laureates whether you're male or female, because there aren't many female Laureates.

Bouchard: Now you are talking about experiences in adulthood, not developmental phenomena. The tremendous accomplishments made by groups for whom it's hard to pin down role models show that role models are certainly not a necessary condition. When role models are invoked there's usually no adequate control. People go through the data and find what they want. Each of us is in contact with large numbers of people, so you can always find a role model. We need controls.

Gardner: Some people at the top of their fields don't have contemporaneous role models. They have what Dean Simonton calls paragons and exemplars. Obviously, you can talk about this empirically if you have instances where it doesn't happen. The fact that Simonton was able to distinguish biographically between cases in which you can point to somebody the person knew, who was older than them, and those where you can point only to someone they knew from the historical record shows that it is possible to study this.

Freeman: Doctors' children become doctors, lawyers' children become lawyers. There is plenty of evidence there for the effects of role models who are close to the child, and plenty of controls, children of similar potential in differently oriented families who are more likely to follow the careers with which they are familiar.

Bouchard: That is not true in all cases. The correlation is much less than 1.00. You have to do adoption studies to get a proper answer to the question.

Gruber: If you were considering Darwin's life, it would be ridiculous not to talk about Henslow, his teacher at Cambridge, Humboldt, a person he greatly admired, and Lyell. Then you get to Wallace. Darwin was Wallace's role model.

Atkinson: Tom Bouchard was responding to a definition of a role model as someone of the same sex and the same socio-economic background.

Bouchard: The term role model is used in a highly specific way, but I would argue that this idea has not been carefully conceptualized at a scientific level. Of course there must be a teacher around, of course the context has to be there, of course you have to acquire the material. I would like to see somebody do a really careful scientific review.

Stanley: Would you advocate studying students who weren't Darwins, for example? Many studied with Henslow, but only one Darwin emerged.

Gruber: Darwin was known at Cambridge as 'the man who walks with Henslow', while the others were not. We need a careful study of how being a role model works, but specifically in the case of highly creative people. The relationship between Darwin and his role model was very warm—he was more than simply a teacher in a classroom who taught Darwin what he needed to know. Tom Bouchard said you have to have a teacher, but there's more to it than that—you have to have a teacher with whom you share something like a love relationship.

Hautamaki: Attachment learning (Minsley 1985) is the term I would use to explain why in a classroom situation some teachers are more capable than others of instilling long-term commitments in their students. A student who allows a mentor or a teacher to work with his values and goals, making sense of the world, is also ready to engage in long-term work. Teachers are not normally given such a possibility by the child, but sometimes the 'doors' open. Parents have that attachment relationship with their children all the time, but teachers seldom do. In Finnish schools, the relationship of pupils with the teacher is value- and goal-neutral, but sometimes attaching situations or teachers will encourage even normal children, not only the able, to engage in long-term commitments.

Freeman: Alice Miller, the Swiss psychoanalyst, uses the term 'witness' (Miller 1981). This is not quite the same as a role model, but somebody who stands up for the child, usually the mother, giving the child a sense of self and authority with which to set forth.

Bouchard: That's very different from a role model.

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