Ability and Creativity: Their Role in Science and Technology

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Introduction

Are exceptional scientific and/or technical achievements the product of ingenious recognitions that are due to "higher" inspirations or enlightenments as the ancient demon theory or the genius myth from the 17th century suggested? Even the "surprise effect", e.g. insight or novelty effect in productive thinking had its roots in older ideas about genius. These were the precursors of current creativity concepts postulated in the first half of this century especially by Gestalt psychologists. They view so-called "aha" experiences as sudden, more or less irrational jumps in recognition (versus psychoanalytically seen as stemming from the unconscious). And even in the modern coincidence-based concepts of creativity (e.g. Simonton, 1988a), the idea of genius is recognizable. This and other "myths" were critically analyzed by Weisberg (1986, 1993). But he, too, was unable to provide satisfactory answers to the following questions: What differentiates provable exceptionally successful researchers and inventors like Newton, Edison, Kekulé, Einstein or Oberth from less creative scientists or technicians? Is it simply banal character differences in interests, task commitment, achievement motivation, perseverance, etc.? Edison once said "Invention is 1% inspiration and 99% perspiration." Goethe, too, the famous German writer, said "Genius is work". Is it true, then, that all great scientific - and artistic - achievements as well as epochal inventions are just due to trivial human and perhaps also coincidental factors as Weisberg and others have recently tried to prove?

I will approach these and other questions in the following. The emphasis will be on using the psychological perspective to find answers. A more complete problem description would necessitate the inclusion of neuroscientific and philosophical questions which can barely or not at all be approached here. On the other hand, educational aspects of giftedness and creativity nurturance should be discussed as well as diagnostic problems. The focus of my presentation is thus on questions of the theoretical conceptualization of the hypothetical constructs "scientific ability" and "creativity", their operationalism and corresponding measurement problems. In addition to newer research paradigms and models, empirical results of current research on giftedness and creativity research will be presented which help explain and predict exceptional achievements in the areas of science and technology. In connection with this, questions about the development and nurturance of mathematical-scientific and technical talent as well as the role of the social learning environment including cultural influences on the development of giftedness and creativity will be dealt with.

Finally, sex-related problems will be discussed in the context of this presentation. Thus, there are five main topics, upon which I will focus:

1. Giftedness and creativity characteristics as individual determinants of outstanding achievement in the field of science and technology.
2. Social and cultural conditions of the development of domain-specific competencies and achievements in science and technology.
3. Development of achievement eminence in light of modern life-span research and sex-related differences.
4. Integrative approaches to the identification of highly able and creative students with regard to science and technology.
5. Supportive surroundings and social conditions for augmenting scientific ability and creativity.

Giftedness and creativity characteristics as individual determinants of outstanding achievement in the field of science and technology

The hypothetical construct "scientific ability" can generally be defined as the ability to scientifically solve problems. More closely defined, this means special talents for excellent abilities in a (natural) science field or subject (such as physics). Whereas this primarily means competencies which are subsumed under so-called convergent thinking, today, mainly functions of so-called divergent thinking are associated with this differentiation goes back to a suggestion made by Guilford (1950). Frequently, contradictory opposites are postulated with the usual concept differentiation. This is despite Guilford's intention of more contrasting, i.e. not mutually exclusive but complementary, intellectual cognitive processes. It is characteristic of convergent thinking, that is the classic intelligence test items, that they call for single-track (inductive, conclusive) reasoning. In open-ended problems with relatively unstructured goals - as employed in creativity tests - divergent thinking tends to be provoked. The problem structure then can be more or less restrictive, i.e. including "closed" or "open" types of problems.

As Facaoaru (1985) was able to demonstrate, there are not only these two prototypes. In the field of science and technology, mixed types are typical of difficult, complex problems (see Table 1).

Structuredness of problem situation	Structuredness of final condition	
	open: several solutions	*closed:* one solution
open: few restrictions	Field A divergent tasks (tests for divergent thinking)	Field B discovery tasks (divergent-convergent tasks)
closed: many restrictions	Field C construction tasks (convergent-divergent items)	Field D convergent tasks (usual intelligence tests)

Table 1: Basic types of problem situations, arranged according to the degree of structure from beginning and final condition of a solution (according to Facaoaru, 1985, p. 60; also see Krampen, 1993, p. 13)

The systematic of various types of problems shown here implies the assumption of qualitative differences in the corresponding thought processes. These qualitative different facets of problem solving represent complementary thought and action strategies. Thus, at the beginning of a complex problem-solving process, primarily divergent (creative) abilities - for example, to generate hypotheses - are necessary and then increasingly divergent-convergent or convergent- divergent and convergent thought competencies are necessary for making hypothesis decisions. In order to build a model of more complex, challenging problem solutions, multidimensional ability and creativity concepts are necessary.

One-dimensional ability concepts hardly play a role in newer intelligence and creativity theories and are not adequate to describe the rich facets of most problems in the field of science and technology.

This contrasts with still frequently found methods of diagnostic practice. For examples of recent theories, I refer here to Gardner's (1983) Theory of Multiple Intelligences, Sternberg's (1985, 1991) Triarchic Theory, Gagné's (1985, 1991, 1993) Differentiated Model of Giftedness and Talent, or the Munich Multidimensional / Typological Giftedness Model (Heller & Hany, 1986; Heller, 1990, 1991b; Perleth, Sierwald & Heller, 1993; Perleth & Heller, 1994). In addition, convergent and divergent factors are the main elements in Sternberg & Lubart's (1991) Investment. Theory of Creativity or in the domain-specific (hypothetical) Model of the Causal Factors of Technical Creativity by Hany (1994), together with noncognitive personality characteristics (e.g. interests and motives) as well as social-cultural determinants. For an interactionist perspective see Sternberg & Wagner (1994).

Numerous empirical studies in the psychometric paradigm have been carried out on scientific ability and creativity. In recent years, cognitive psychological (experimental and semi-experimental) studies have also been carried out. Since I have reported in detail on these elsewhere (Heller, 1993), I will only briefly describe the most important results here.

The most frequently referred to aptitude-traits are formal-logical (convergent) cognitive abilities, ability to think abstractly, systematic and theoretical thinking, etc., but also richness and fluency of ideas, ability to restructure the problem (flexibility), originality of solution methods and products (in the sense of more divergent thought production). On top of these come the following non-aptitude-traits such as intellectual curiosity or thirst for knowledge, exploratory drive, and desire to raise intellectual questions, intrinsic achievement motivation, task commitment, goal orientation, persistence, as well as tolerance for ambiguity, uncertainty and complexity, nonconformity, etc.

In addition to the general, that is more or less domain-overlapping and situation-independent postulated personality determinants of achievement eminence in the field of science and technology, recent experimental psychological studies supplement the above lists of characteristics with important domain-specific process characteristics. This is to be briefly reported in the following.

Van der Meer (1985) carried out process-oriented analyses of mathematical scientific achievements in the Klix Paradigm "experimental diagnosis of giftedness". These were supposed to provide information about individual differences in mathematical-scientific problem - solving. The main purpose was to isolate such psychological mechanisms which are the cognitive process responsible for such achievements.

Substantial characteristics of giftedness according to Klix (1983) are, on the one hand, the individual ability to reduce a problem's complexity and, on the other hand, cognitive expenditure of energy in solving the problem. In this, the task-oriented motivation is felt to play a key role: "The role of this task-oriented motivation consists mainly of creating and maintaining an activity level necessary for an effective search, assimilation and processing of relevant information up to and including finding a solution (Van der Meer, 1985, p. 231; author's translation).

In a manner similar to Sternberg's component analysis, Van der Meer uses tasks where inductive or rather analogous thought is necessary. Analogous conclusion processes are to be found in the recognition and transfer of relations between topics from one area to another. The medium for the analogies are chessboard-like patterns of varying complexity.

The most important result was the proof that gifted secondary school students (specially nurtured in mathematics classes at the Humboldt University of Berlin) were significantly better at solving such analogy test items than a control group of average students. Further characteristics for mathematically-scientifically gifted according to Van der Meer's results were a significantly higher information-processing speed with regard to basic cognitive processes as well as a lower, that is more economical solution effort. This indicates more effective solution strategies. These contain minimal interim memory of partial results (in the working memory) which make up the higher quality of thought processes in the gifted. Van der Meer considers the superior style of connecting basal operations as well as the increased simplicity and effectivity of finding solutions to be significant characteristics of scientific ability.

In addition, Facaoaru (1985) and Rüppell et al. (1987), who also used cognitive psychological bases in their integrated research approaches, analyzed divergent - convergent thought processes. These are especially important with regard to innovative solutions in technical-creative areas (cf. also Necka, 1994). Others have studied characteristics of cognitive style, whereby an *innovative style* of problem solving in changing perspective, in breaking through given problem structures or rather restructuring the problem area as well as considering alternative solutions during the decision process were demonstrated. Rüppell (1992, 1994), who attempted to use his DANTE - Test (DANTE means Diagnosis of the Astute Natural-scientific Engineering Genius) to measure relevant *qualities* of human information processing in science and technology, sees the "heart of complex problem solving and creative thinking" in the following process characteristics (Rüppell, 1994, p. 298): structural analogy sensibility, procedural analogy sensibility, selective elaboration, logical coordination capacity, structural or spatial-visual flexibility, and synergetical thinking.

"As these Qualities of Information processing (QI) are poorly covered by classical tests of intelligence, DANTE can be regarded as their necessary complement. 'QI instead of IQ' or 'constructive processes instead of static abilities' must be the paradigmatic motto if one tries to identify outstanding problem solvers or even inventive geniuses" (Rüppell, 1992, p. 138).

In order to *generate hypotheses* - according to Einstein the most important step in the problem-solving process - the hypothetical concept *"science discovery"* was postulated by Langley et al. (1987), who presented many results in their treatise. Similarly to the concept of "wisdom" from the life-span approach to exceptionality (Baltes & Smith, 1990; for an overview refer to Sternberg, 1990), the concept "cleverness" suggested by Hassenstein (1988) is a synthetic approach for the giftedness phenomena being discussed here. It suggests a combination of knowledge, a perceptual exactness in observation, good memory and logical-abstract reasoning, richness of ideas, fluency in associations and fantasy, as well as flexibility and inner drive with regard to motivation etc. Cropley (1992) calls this "true giftedness" in order to indicate that creativity is an essential part of giftedness; cf. also Gardner (1988, 1993), Matyushkin (1990), Runco & Albert (1990), Ramos-Ford & Gardner (1991), and generally, Glover et al. (1989).

The value of expertise research is that the role of *knowledge acquisition* in the development of domain-specific competencies was pointed out. For the initial phase of expertise acquisition, the precedence of motivation (Hayes, 1989) and subject-interest (Ericsson et al., 1990) over cognitive abilities was emphasized. On the other hand, one should not overlook the fact that motivation and cognition represent essential individual learning determinants in the development of expertise, i.e. the performance at a very high level (Schiefele & Csikszentmihalyi, 1994). Researchers on expertise often underestimate the importance of cognitive abilities (cf. Ericsson et al., 1993). And finally, there is the flexible use of subject-related expertise without which it would seem impossible to have innovative solution processes and creative products in science and technology (cf. Waldmann & Weinert, 1990; Weisberg, 1993). In conclusion here, a recently proposed hypothetical model by Hany (1994) for explaining technical creativity should be reviewed. This serves as a basic model for the German-Chinese (Munich-Peking) cross-cultural study that I will be referring to in my next point.

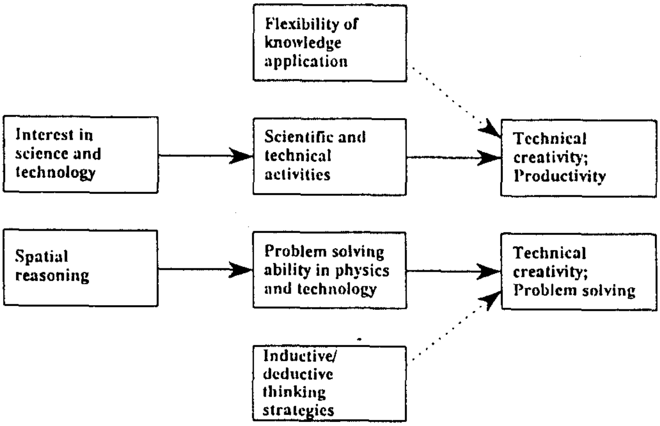

Fig.1. Causal model of technical creativity (by Hany, 1994, p. 143)

Social and cultural factors in the development of domain-specific achievements in science and technology

Whereas the previously presented studies focussed on *individual* determinants of outstanding achievement in science and technology, more recent *synthetic* approaches consider social-cultural determinants more and more, e.g. Gardner (1988), Haensly & Reynolds (1989), Sternberg & Lubart (1991). In addition to the importance of *situational* variables or even *coincidental* factors (Simonton, 1988a/b, 1991, 1994; Heller & Hany, 1986; Heller, 1990, 1991b; Feldman, 1986, 1992; Perleth & Heller, 1994), the role of so-called *creative learning environments* and *social* influences on the development of scientific ability and creativity are emphasized in recent studies from the field of social psychology. Favorable and unfavorable developmental socialization influences on giftedness have primarily been studied in the social settings of the family, school, leisure time resources and the professional areas (Amabile, 1983; Tannenbaum, 1983; Gruber & Davis, 1988; Csikszentmihalyi, 1988; Runco & Albert, 1990; Csikszentmihalyi & Csikszentmihalyi, 1993). In this respect, not only stimulating social learning environments, experimental possibilities, available information and community resources are important, but even more important are experts as "creative" models for the development of scientific ability and creativity. Linn (1986) emphasized here the necessity of new science curricula which is specially tailored to the needs of gifted adolescents. The didactic concept "discovery in science learning" was named as perhaps the most important postulate by gifted educators, e.g. Davis & Rimm (1985), Kirk & Gallagher (1986), Zimmerman & Schunk (1989), Colangelo & Davis (1991), Cohen & Ambrose (1993), Goldstein & Wagner (1993). This means that individual problem-solving competencies together with domain-specific knowledge should be mediated or supported by autonomous learning. Refer to Colangelo et al. (1993), Pyryt et al. (1993), Subotnik & Steiner (1994) for projects and gifted programs in the field of science and technology.

With respect to science and technology as fields of leisure time activities in adolescents, we found significant differences in the Munich longitudinal study of giftedness (Heller, 1991b, 1992b; Perleth & Heller, 1994) between highly intelligent and highly creative students with regard to technology, but not with regard to science (Figure 2). This corresponds to another result from the same study where the intellectually gifted students received the best grades in math and physics, while the intellectually *and* creatively gifted were the best students in the other subjects, especially in German (native language).

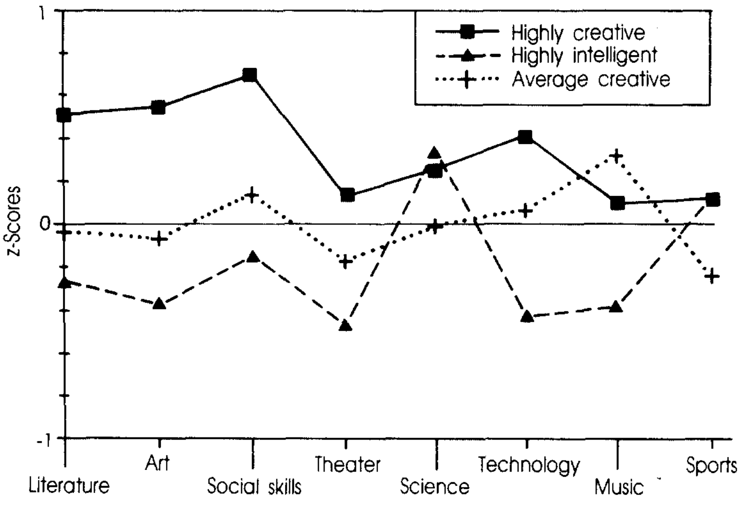

Fig. 2 Differences between students of high and average creativity as well as high intelligence with regard to extracurricular activities (according to Perleth & Sierwald, 1992, p. 242).

With respect to adulthood, the following results from a cross-national study on technical creativity (Hany & Heller, 1993; Hany, 1994) may be of interest for identifying *cultural influences.* Figure 3 shows the average of the subjects from three countries in the point scales of the Unfolding Test (convergent thinking) and the Construction Test (divergent thinking). We see that the subjects from the Oriental culture are superior in convergent thinking but are below average in divergent thinking (interaction scale-nationality: F=26.7; p<.001). The performance profile of the

Germans is a mirror image of this although less distinct. The US engineering students were poorer on both scales. Similar findings stem from Moritz (1992, 1993) and Tan, who is studying people's conceptions of technical creativity across culture in her doctoral dissertation (Tan, 1992, 1993). For implicit theories in this and other domains cf. Sternberg (1985).

Particularly enlighting is the positive combination of convergent and divergent thinking processes in the sample of Japanese engineering students, who in Figure 4 are most strongly represented in cluster 1. What could not be seen in the preceding Figure 3 (since the Japanese subjects also make up the largest part in Cluster 4), becomes clear here in Figure 4 and may be an explanation for the astonishing technological successes of the Japanese worldwide. Japanese engineers seem to be optimally able to combine convergent and divergent thought competencies when solving technological problems. The relationship between the clusters (using the method from Ward) and culture was found to be highly significant.

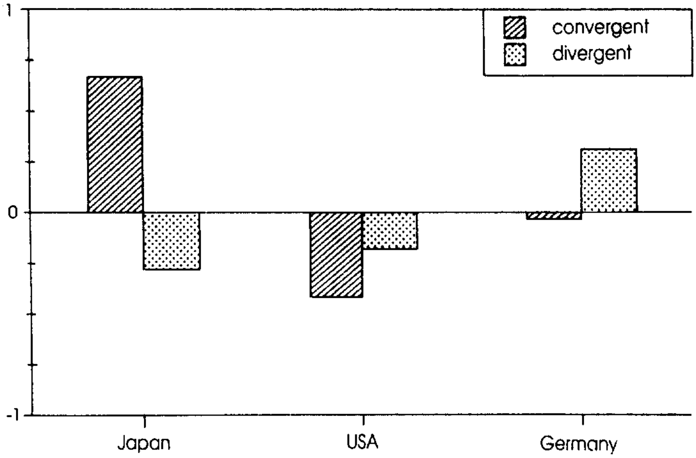

Fig. 3. Performance differences in Japanese, U.S. and German engineering students. The scales for convergent and divergent thinking were standardized in order to make comparisons possible (according to Hany & Heller, 1993, p. 108).

The following Figure 5 shows the relative distribution of three culture-specific samples in the four clusters. The clusters are arranged according to their means on the scale for divergent thinking.

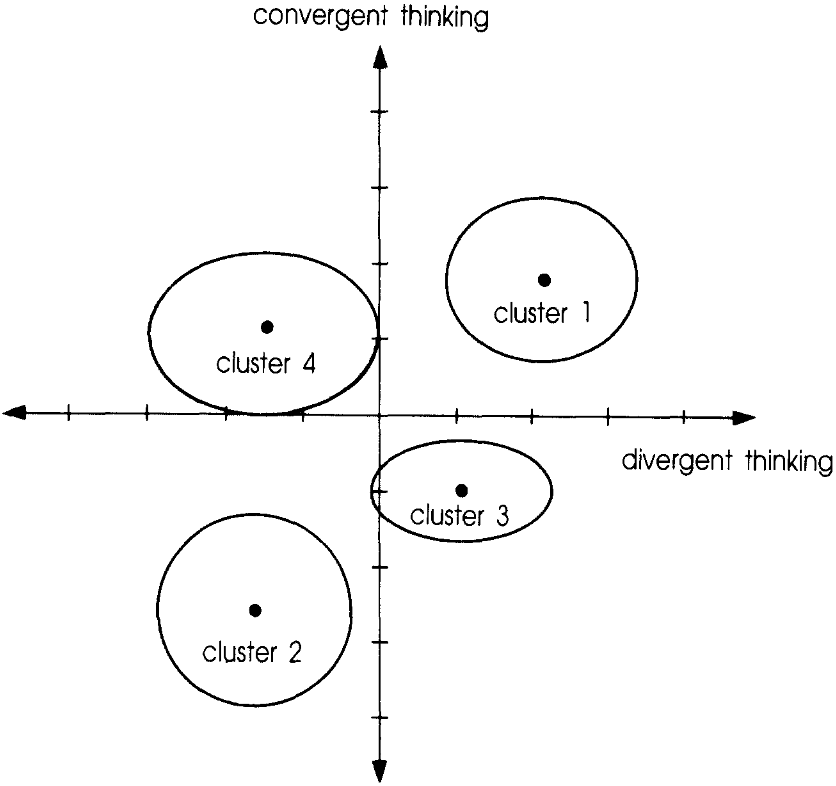

Fig. 4. Graphic presentation of the four cluster solution for the frequently distribution in the dimensions "convergent" and "divergent" thinking. The vertical and/or horizontal diameter of the ovals surrounding the cluster averages correspond to two standard deviations of the cluster group (according to Hany & Heller, 1993, p. 110).

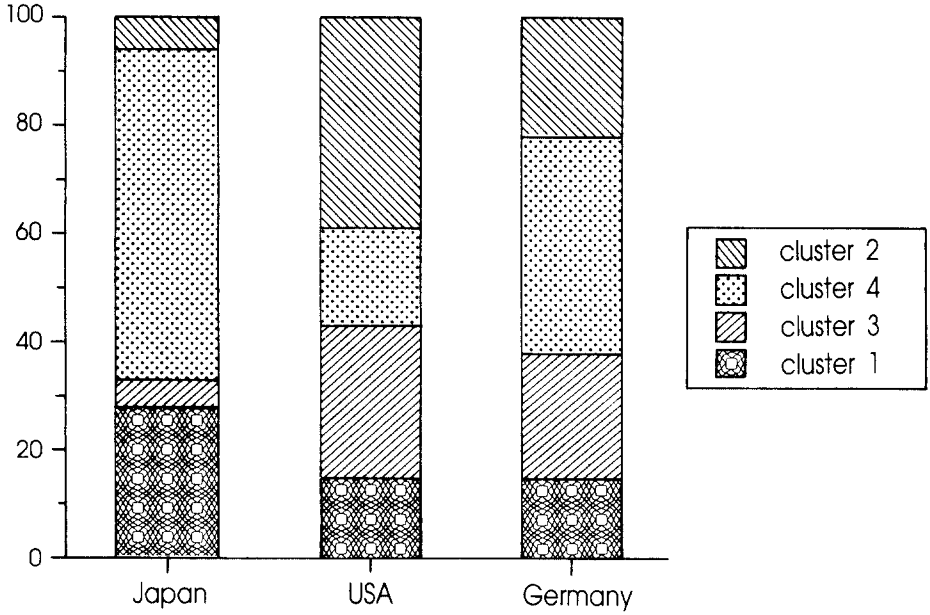

Fig. 5. Relative distribution of the three samples in the four clusters for convergent vs. divergent thinking (according to Hany & Heller, 1993, p. 110).

Development of achievement eminence in view of modern life-span research and sex-related differences

Whereas in earlier decades the developmental psychology focussed on childhood and adolescence, more recent research considers the entire life-span from infancy to late adulthood; cf. Baltes (1973, 1987), Baltes & Schaie (1973, 1976), Thomae (1976), Santrock (1983), Mönks & Spiel (1994). Figure 6 emphasizes the differences between traditional developmental psychology and modern life-span research (based on Santrock, 1983).

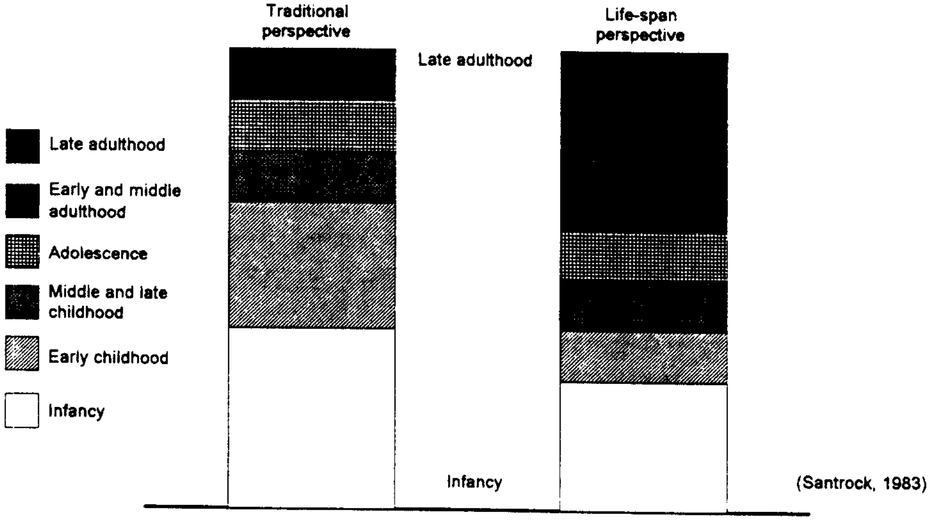

Fig. 6. Traditional versus life-span research approaches to human development (according to Mönks & Spiel, 1994, p. 136).

These authors summarized the following main characteristics of the life-span perspective (Mönks & Spiel, 1994, pp. 137-138) cited below:

- Life-long development: Development as a process of change takes place throughout the whole life; no age period dominates development.
- Multidimensionality: Human development consists of different dimensions and different components within these dimensions.
- Multidirectionality: Some dimensions or components may increase, while others decrease.
- Plasticity: Development may take different paths, depending on the individual's life conditions.
- Historical embeddedness: Development is influenced by historical as well as economical and cultural conditions.
- Contextualism: The individual is responding to and acting on contexts; heredity is not a fate but is always "heredity in a specific environment" (Vossen, 1992, p. 92).
- Multidisciplinarity: Development needs to be studied in an interdisciplinary context.

These principles are not only generally true, but also with regard to the development of domain-specific competencies and performances. I have chosen as examples to present here the results from two recent studies that are particularly interesting with regard to science and technology. In the first case, sex-related differences are referred to which stem from the above-cited German-Chinese cross-cultural study on the development of technical creativity in school children. Hany (1994) summarized the results from a developmental psychological point of view:

(1) In the younger people (secondary school level), creative performance could be differentiated into "divergent" and "convergent" aspects of problem-solving competency. The *quantity* of creative problem solutions depended primarily on "motivational factors, practical experience and flexibility of knowledge application", the *quality* more on "problem-solving ability, spatial thinking and thinking strategies" (Hany, 1994, p. 144). Even though the well-known hypothesis of two kinds of productivity could be confirmed for the younger (eleven and twelve-year-old) subjects, the two forms of problem solving seem to interact more strongly in older students (from about the 7th and 8th grades upward).

(2) Highly intelligent young adolescents differed from agemates of average intelligence primarily in the predictors and components of technical creativity. The highly intelligent individuals also showed a higher quality in their solutions. It could be proved that they did not need extensive practical experience in order to cope with technical problems. Apparently they are "able to combine formalized instruction (as in school) with paradigmatic learning experiences, and then, in turn, to flexibly combine the resulting physics and technology knowledge with more general problem-solving strategies" (loc cit.).

(3) Although the female students did not score better than the males on the *quality* of technical problem-solving solutions, the girls clearly scored better than the boys in the *quantity* of solutions. Perhaps, this is due to the fact that the less intelligent females relied on general thinking skills whereas the more intelligent used practical experiences with technical problems and problem-solving competences. In addition, the following developmental changes of the subgroup means of the residuals of the criteria were revealed (see Figure 7).

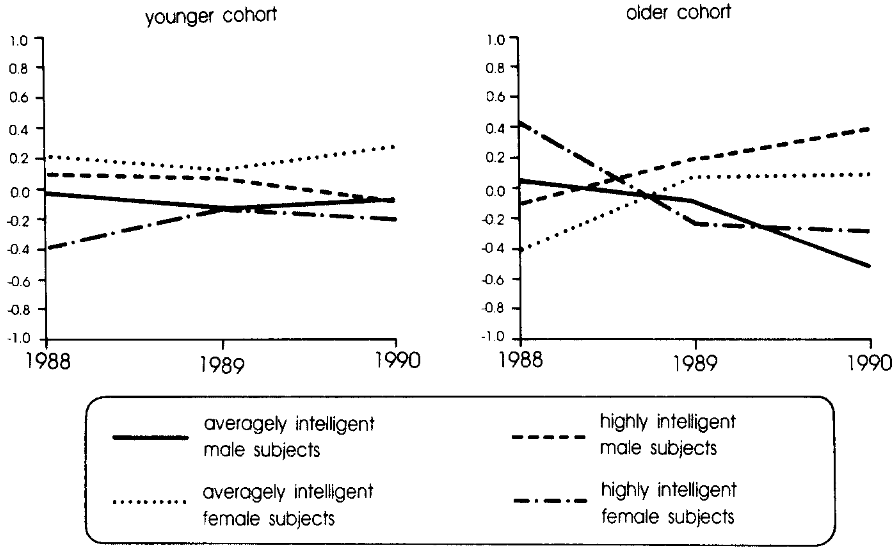

Fig. 7. Changes in the residuals of problem-solving ability in physics and technology for the German subgroups after deleting the main effects of age cohort, gender, intelligence, and the regression on the predictors - in order to analyze interaction effects (according to Hany, 1994, p. 140).

In the newer approaches to creativity in science and technology, both divergent thinking processes and convergent cognitive abilities interact together. Hence we must not ask whether but how both cognitive components interact during the solving of difficult complex tasks. Which role do context variables and chance factors play in the life-span development of exceptionality?

The most recent models of giftedness and talent are characterized by their increasing complexity, e.g. Gardner's (1983) frame of mind, Gagne's (1991, 1993) differentiated model, Sternberg's (1993) pentagonal model of (implicit theories of) giftedness, the Munich multidimensional/typological model of giftedness (Heller & Hany, 1986; Heller, 1990, 1991b, 1992b; Perleth, Sierwald & Heller, 1993) or Simonton's (1988) chance-configuration theory. Simonton, who in his most recent studies attempted to summarize historiometrically (1990, 1991, 1993, 1994) the "connections between life-span development and differential creative achievement" especially emphasized the following characteristics of eminent creators (1993, p. 26): typical career trajectories, the relative importance of career age versus chronological age, the role of interdisciplinary differences, the impact of individual differences in creative potential, and the possible resurgence of creativity displayed in the "swan-song" phenomenon. His algorithm related to the first and last career landmarks of exceptionality in the life-span most surprising findings. Further investigations in this field should consider theoretical aspects of general and educational psychology as well as differential psychological perspectives in later life course analyses. Simonton's (1994) statistical explantation of the data-based patterns in his career analyses of geniuses is plausible and the effect surprising. Now it would be most interesting to develop a comprehensive model which could explain why some persons realized creative lives and others - with comparable creativity potential - did not. Such a framework would be a new milestone, and not only theoretically desirable but also relevant to the practice of gifted education and nurturing talented people in the life-span perspective.

Integrative approaches to the identification of highly able and creative students with regard to science and technology

The psychological picture of scientific ability and creativity, especially the conditions under which they develop and process characteristics call for multimethod diagnostic approaches. Since more recent theories of giftedness and creativity assume multidimensional concepts, the diagnostic strategies - if they are based on the theories - must take this into consideration. This holds true for individual diagnoses (in school and career guidance or counseling) as well as for identification methods for selecting students for particular programs. Particularly with regard to applications in gifted and talented education, multiple giftedness and creativity theory-based multidimensional diagnostic approaches have advantages over one-dimensional models. Such open, complex approaches do, however, contain the risk of a number of measurement problems, in particular, lower reliability than one-dimensional IQ tests. But the discussion about this often neglects the aspect of ecological validity which is generally higher in differential tests. The guaranty of this validity is, however, essential within the context of gifted education. Multimethod approaches can decrease the reliability problems if diagnosis is carefully planned.

The objection raised by Shore & Tsiamis (1986), who doubt the usefulness of talent sources - i.e. formal identifying procedures - is even more serious, as is their preference for informal procedures such as nomination. Meanwhile Gagné (1989, 1991) was able to show convincingly that peer nominations and similar alternatives to standardized tests did not adequately meet psychometric standards, and thus do not present a realistic alternative to formal identification procedures. Additional useful diagnostic information can be provided by peer nomination in older adolescents or adults. This also seems to be true of diagnostic interviews or explorations, teacher ratings and checklists etc. (cf. Funke et al., 1987; Hany & Heller, 1990; Hany, 1993a; Feldhusen & Jarwan, 1993). Multiple methods in diagnosis indicate the use of various sources of information, i.e. test, questionnaire and life data in the sense of Cattell (1965). Both the selection of the indicators or predictors of giftedness and the definition of the criteria that is to be explained or predicted depend on the possible use of diagnostic results. This demand is generally true and especially for the identification of highly gifted and talented in science and technology (Heller, 1989, 1993). It is self-evident that the usual test standards must be met here as well. Although scientifically tested identification strategies and measurement instruments based on differential models of giftedness are available (cf. Heller & Feldhusen, 1986; Callahan, 1991b; Richert, 1991) and also domain-specific test batteries (cf. Heller et al., 1985; Heller, 1989, 1992; Perleth & Heller, 1994; Hany, 1994, or Cho, 1992, 1994), there is still frequently a huge gap beween the current scientific recognitions and the practice of identification. This is even more regrettable since we have relatively accurate information about relevant predictor-criteria relationships from several large longitudinal studies (Benbow & Stanley, 1983; Stanley & Benbow, 1986; Mönks et al., 1986; Stanley, 1993; Lubinski & Benbow, 1994; Zuckerman, 1967, 1977, 1987, 1992; Trost, 1986, 1993; Albert, 1992, 1994; Heller, 1992b, 1993; Hany, 1993b; Perleth & Heller, 1994; Gross, 1993; Walberg et al., 1994; Subotnik & Arnold, 1993, 1994; Yontar, 1994). See also Koren (1994), for a current review. Koren refers to both status diagnostic and process diagnostic methods. The most poorly explained relationships are those between early signs of creativity and ultimate achievement in adulthood, as the most recent analysis of seven case studies (geniuses) by Gardner (1993a/b) again documented. Also see Bloom (1985).

Supportive surroundings and social conditions for augmenting scientific ability and creativity

The development of scientific ability first depends on *individual* determinants such as intellectual or creativity potentials, intrinsic achievement motivation, cognitive curiosity and (domain-specific) interests. With increasing activities in the field of science and technology - more or less domain-specific - declarative and procedural knowledge is acquired that can lead to various levels of expertise or achievement eminence. In order for such a development to be possible, frequently so-called *creative learning* environments are necessary. This is understood to be stimulating the cognition and supportive social-emotional relationships, i.e. the family and school or professional socialization conditions, stimulating peer group interactions or the chance to use material resources as they are adapted to the individual's learning and knowledge requirements. Finally attitudes, expectations and value systems in the social settings play an important role in the development and nurturance of gifted and talented youth (Gallagher, 1991). For information about various gifted programs see Cropley (1991, 1992), Colangelo & Davis (1991), Walberg & Herbig (1991), Urban (1990, 1993, 1994), Necka (1992), Hany (1992), Shore & Kanevsky (1993) and other contributions to the International Handbook of Research and Development of Giftedness and Talent (Heller et al., 1993). With special attention to the field of science and technology cf. Wieczerkowski & Prado (1993), Pyryt et al. (1993), Cho (1992, 1994). Curriculum problems are dealt with by Davis (1991), O'Neil et al. (1991), Gallagher & Van Tassel-Baska (1992), Van Tassel-Baska (1993) and Van Tassel-Baska et al. (1993). For those interested in sex-related differences in the field of mathematics, (hard) sciences and technology, refer to the newest information by Dix (1987), Callahan (1991a), Beerman et al. (1992), Heller (1992a), Benbow & Lubinski (1993), Lubinski et al. (1993), Stanley (1993), Brody et al. (1994), Goldstein & Stocking (1994). The situation in the Asian-Pacific area is described in the handbook contributions by Wu & Cho (1993) and Zha (1993).

Finally, one should not overlook the fact that social events and chance or coincidental factors can play a decisive role in the scholastic and professional careers in the field of science and technology. There have been both theoretical models of creativity and giftedness as well as numerous empirical research results, especially from biographical analyses of brilliant researchers and inventors (Feldman, 1986, 1992; Simonton, 1988b, 1991, 1994; Heller & Hany, 1986; Heller, 1990, 1991b; Perleth & Heller, 1994).

In conclusion I would like to focus on a few surrounding conditions which seem to be important - from a psychological point of view - for the development of competencies and performances in science and technology. I base this on a talk I gave at the Korean Educational Development Institute (KEDI) in 1991 in Seoul which was published in the same year in Korean (Heller, 1991a; cf. also Heller, 1993, p.146-147). Creativity can be considered within the more comprehensive concept of *cognitive competence*. This concerns the complex achievement forms of problem perception, information processing through learning transfer and divergent-convergent thought processes in various situations. Creativity is generally expressed, for example, in technical areas through original processes, new methods, useful inventions and valuable products. Analogously, scientific eminence manifests itself in creative questions and the development of solution-relevant hypotheses with regard to scientifically unsolved problems, the development of new theories and methods and original problem solutions.

A primary task of formal (school and university) education is, therefore, to mediate necessary subject knowledge in science and technology and to demonstrate how this can be flexibly employed, that is, also in unconventional ways and individually challenging manners. As experiences and results from the research with the gifted have shown and with results on expertise, creative models have an important function in such processes of scientific or technical competency acquisition.

If one compares proven stimulating and successful university institutions or research laboratories with those lacking such an effect, the following characteristics become apparent: a high degree of task orientation and demanding levels combined with openness to new ideas; in addition a preparedness to critical-constructive discussion and a balanced group dynamic between solidarity and competition among the team members (Amabile, 1993; Weiner, 1990).

If a basic consensus exists among the team members about the research ideology, *interdisciplinary* or *intradisciplinary heterogeneous* research teams offer the most favorable conditions for creative achievements in science and technology (Weinert, 1990). In addition to increasing subject and methodological expertise, the increased ability to change perspectives is a favorable condition for scientific productions and technical inventions. Above and beyond this, an open partnership cooperation between younger and older scientists provides the opportunity for mutual stimulation, fruitful interchanges and desirable compensation effects with regard to various experiences and knowledge. The ideal situation would lead us to expect an accumulation of individual expertise. The finding that a combination of task commitment, joint responsibility and relaxed working atmosphere substantially contribute to creativity and research productivity is well founded.

In recent years, the question of sex-related differences in giftedness and achievement in science, mathematics and technology has been reopened, particularly in Europe and North America.

The observed sex differences are primarily found in the "hard" sciences (physics, astronomy, etc.) and in mathematics as well as in engineering. This especially relates to the space and quantitative factors of cognitive abilities where girls and women generally score lower in test items. Interestingly, numerous recent results from research on the gifted have shown that the differences described increase with increasing level of ability (scissors effect). A complete literature review of this field (Beerman et al., 1992, also see Benbow & Lubinski, 1993; Lubinski et al., 1993; Stanley, 1993) indicates that these sex-related differences are primarily motivational and social-culturally caused, that is less dependent on ability differences. However, the current discussion, even among the experts in the field, continues to be filled with controversy (cf. Bock & Ackrill, 1993). In my opinion, nurturance attempts for scientifically and technically talented girls should focus on changing the individual causal attributions of success versus failure. There is much evidence that females (as compared with males) tend toward unfavorable, that is poorer self-concepts which need to be changed in terms of motivation and action strategies toward self-concepts that are more favorable. For this purpose, we are currently carrying out a semi-experimental reattribution study (Heller, 1992a).

Finally, I would like to briefly discuss the question of age dependence in exceptional achievements in the field of science and technology. Lehmann's results from the year 1953 that the most important research contributions of creatively outstanding scientists were mostly made before they turned 40 could not be overturned in successive studies (e.g. Zuckerman, 1967, 1987, 1992) despite a number of methodological problems. Even the explanation attempts where in the middle age range the competitive responsibilities in areas such as management and representation increase while research productivity decreases, do not hide the fact that originality, in particular, fades. It may be true, then that varying influences of career motivation, age-dependent increases in workload, aging of subject knowledge previously acquired, etc. cause age-correlated losses in creativity, although Simonton (1988, 1991, 1993, 1994) and other researchers emphasize the great individual variation with regard to creativity. This should not be overlooked in the discussion.

A more satisfactory - at least among the older members here present - interpretation of the suspected change in abilities mentioned is offered by Mumford & Gustafson (1988). Young adults are supposed to tend more than older adults to solve difficult tasks by integration and reorganization of separated cognitive structures - a thought style which is favorable in many sciences for the finding of new results. Individuals in middle and higher age groups tend more to pragmatic solutions (cf. Weinert, 1990, p.40) based on field-dependent experiences and domain specific knowledge.

Such an explanation on the basis of qualitative differences in problem-solving strategy would emphasize indirectly again that both main components - creativity and scientific ability - are essential personality determinants that have to be interrelated with "creative environments" in favorable situations.

Acknowledgement

I wish to thank Dipl.-Psych. Colleen S. Browder for her assistance in the translation of this paper.

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