3 Manifestation of Creative Behaviors by Maturing Participants in the Study of Mathematically Precocious Youth

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Abstract

The creative performance of mathematically apt adolescents was investigated. In order to provide a framework for the identification and evaluation of the predictors of creative behavior reported by SMPY students, two empirical studies based on SMPY data were reviewed briefly. A summary of the statistical results of the first three talent searches and of the follow-up showed that SAT-M score is negatively related to participation in science fairs for girls and positively related to participation in mathematics contests for boys. Major attention was given to the problems encountered in analyzing these studies. The ambiguity and inconclusiveness of the results were attributed to substantive limitations associated with the conceptualization of creativity, the operationalization of the construct, and the nature of the learning environment. Methodological difficulties occurring in relation to the unreliability of the measures, the restricted ability range, and the violation of assumptions central to the statistical procedures used were identified. In conclusion, several recommendations for future investigations were offered.

How creatively have the boys and girls identified as being highly talented mathematically by the Study of Mathematically Precocious Youth been performing as they have been maturing? In an effort to answer this important question, the writer examined four volumes that have evolved from SMPY (George, Cohn, & Stanley 1979; Keating 1976b; Stanley, George, & Solano 1977; Stanley, Keating, & Fox 1974), studied a master's thesis (Kusnitz 1978) and a journal article (Albert 1980), and explored for the first three talent searches the statistical relationships between selected antecedent variables (responses to items) in questionnaires employed in the talent searches and those criterion variables (item responses) in follow-up survey forms completed after high-school graduation (Benbow, chapter 2 of this volume) that were thought possibly to reflect creative behaviors. Recent professional literature concerned with the relationship of creativity to giftedness also was consulted to provide additional insights. As had been expected, it became apparent that answering the question would not be easy and that both substantive and methodological difficulties encountered in answering the question would indeed be disconcerting.

In view of the many difficulties encountered, it was decided that following a brief review of two significant empirical studies based on SMPY data and a summary of relevant statistical results from a survey of members of the first three talent searches (approximately four to five years after their selection for participation in SMPY) major attention would be focused upon delineating several major substantive and methodological limitations and then upon suggesting recommendations for future studies that could furnish the kinds of evidence needed to answer the question posed. This approach appeared to provide some promise for facilitating future research efforts that could demonstrate possible relevant relationships between later creative behaviors in mathematics and in science-related activities to antecedent variables such as scholastic aptitude, family background factors, personality characteristics at time of selection, and initial indicators of creative potential.

Two Empirical Studies

In the SMPY endeavor two empirical studies (Keating 1976a; Kusnitz 1978) have afforded some evidence regarding not only the standing of groups of mathematically talented youth on measures of creative behaviors in comparison to that of normative samples but also the extent of the relationship of measures intended to reflect creativity to those indicative of general intelligence, selected abilities, value orientation, vocational interests, artistic preferences, and life-history factors. A brief review of each of these investigations provides a pertinent framework within which statistical results of post-high-school graduation follow-up studies of individuals in SMPY from the first three talent searches can be reported and evaluated.

In his empirical study Keating (1976a) administered to a sample of seventy-two male junior-high-school students who had scored highly in the 1972 and 1973 talent searches several cognitive and affective measures that had been hypothesized as potential predictors of later creativity. These measures were concerned with values, life-history characteristics, preferences for various geometric figures, personality traits, and general reasoning capabilities. Although the findings were somewhat contradictory from one measure to another, Keating demonstrated a strong theoretical-investigative orientation for the group. He concluded that his results supported the feasibility of a multifactor theory of creative behavior that would permit the manifestation of creativity in different ways by different individuals. It was anticipated that longitudinal follow-up studies would resolve questions concerning the long-term predictive validity of several of the measures.

By far the more comprehensive of the two empirical studies regarding the relationship of creative behaviors of mathematically talented students to selected cognitive abilities and affective characteristics was the one completed by Kusnitz (1978). Employing a highly homogeneous (in terms of cognitive ability) subsample of sixty boys between 12 and 14 years of age who had scored at a high but not at the highest level in the fourth annual talent search conducted by SMPY, Kusnitz typically found low and statistically nonsignificant correlations between measures of ability and those measures hypothesized as indicative of creative behaviors. Ability was defined by scores on (a) the College Board's Scholastic Aptitude Test-Mathematics (Educational Testing Service 1948–80), (b) the Mathematics and Natural Sciences Reading subtests of the American College Testing (ACT) Assessment (American College Testing Program 1959–80), (c) the Abstract Reasoning, Mechanical Reasoning, and Spatial Relations parts of the Differential Aptitude Tests (DAT) (Bennett, Seashore, & Wesman 1947–80), and (d) an achievement test – the Cooperative Mathematics Tests: Algebra I and II (Educational Testing Service 1962) – of first-year high-school algebra before it was studied formally. Creative behaviors were revealed by three scores in Fluency, Flexibility, and Originality in the Verbal Test and by four scores in Fluency, Flexibility, Originality, and Elaboration in the Figural Test of the Torrance Tests of Creative Thinking (TTCT), Form A (Torrance 1966, 1974),[1] by standing on each of two scales – Art-Writing and Mathematics-Science – of the Biographical Inventory–Creativity (BIC) (Schaefer 1970), by performance on the Barron-Welsh Art Scale (BWAS) (Barron & Welsh 1952; Welsh 1959;

Welsh & Barron 1963), and by placement on the Watson-Glaser Critical Thinking Appraisal Form (WGCT), Form YM (Watson & Glaser 1964). In addition, Kusnitz explored the relationship between scores on each of these measures representing creativity and those reflecting essentially non-cognitive (affective) components on each of six scales—Theoretical, Economic, Aesthetic, Social, Political, and Religious—of the Study of Values (SOV) (Allport, Vernon, & Lindzey 1970) and on each of the six categories—Intellectual (Investigative), Artistic, Realistic, Conventional, Social, and Enterprising—of the sixth edition of the Vocational Preference Inventory (VPI) (Holland 1965). Somewhat consistent with MacKinnon's (1962) observation that high scores on both the Theoretical and the Aesthetic scales of the SOV were present for a sample of creative mathematicians and scientists was the finding that the scores on the Theoretical scale were significantly correlated with those on the Mathematics-Science subtest of the BIC and that the scores on the Aesthetic scale were reliably correlated with those on the Art-Writing subtest of the BIC.

After relating his findings to those of several investigators whose work he had carefully reviewed, Kusnitz formulated conclusions indicating that (a) students of high mathematical ability within a sample having an extremely narrow range of high (but not the highest) cognitive ability did not constitute a particularly distinguished group in their standing on measures of creativity, (b) measurement of creativity was complex and ambiguous, and (c) the most helpful way to view creativity is through centering attention upon an individual rather than a group. Furthermore, he suggested that use of a comparison group of highly talented students in mathematics in conjunction with one of students with so-called normal ability in mathematics would furnish data that would clarify the nature of the relationship between mathematical ability and creativity. He also urged that tests of creativity be employed as predictors of academic achievement across groups representing different ability levels.

Follow-Up Studies of Students in the First Three Talent Searches

For the follow-up studies involving both boys and girls in the first three talent searches, correlation coefficients were calculated between the ordered (quantifiable) responses to several questions (antecedent variables) in talent-search questionnaires and similarly quantifiable responses to items (criterion variables) on the follow-up survey forms (of which more than 90 percent were returned) (Benbow, chapter 2 of this volume). Items in the talent-search questionnaire dealt with (a) number of siblings of the respondent, (b) his or her birth order, (c) occupational status of the father and the mother, (d) educational level of the father and the mother, (e) degree of liking for school and for mathematics, (f) amount of involvement with others in learning mathematics, and (g) other life-history factors. Questions in the follow-up survey form were concerned with (a) amount of participation in science fair projects, (b) amount of participation in mathematics contests, (c) number of honors or awards received, (d) number of years of involvement in various academically oriented school-related activities, and (e) number of years of association in a host of out-of-school activities (see Appendix 2.1, p. 5 of follow-up survey). Although initially correlations were found only for the whole group, subsequently separate correlations for males and females were determined for selected pairs of variables of greatest interest.

In chapter 2 of this volume Benbow presents comprehensive findings of the interrelationships among several items within the questionnaire and follow-up survey forms and describes how the follow-up study was conducted and analyzed. Only those criterion variables that were thought to be especially relevant to creativity have been included in the data reported for this study. The not entirely unexpected result was this: only 1 of the 655 correlation coefficients calculated between antecedent and criterion variables from the questionnaires reached a value as large as .19. Approximately 18 percent of the coefficients were statistically significant at or beyond the .05 level.

In view of the somewhat disappointing results, it was decided that for each sex a small number of what appeared to be the most nearly relevant and promising criterion variables (number of projects submitted to science fairs and number of mathematics contests in which participation occurred) would be related to each of four antecedent (predictor) variables (level of father's education, level of mother's education, occupational status of father, and occupational status of mother). In addition, the two criterion measures reflecting creativity in science and in mathematics were correlated with SAT-M scores earned by the participants while they were in the seventh or eighth grade (at the time of the talent search) and again while they were typically in the eleventh or twelfth grade, that is, four or five years later in their academic program.

Except for the coefficient of $-.22$ ($p < .001$) between father's level of education and number of projects submitted to science fairs for the sample of girls in the second wave of the follow-up survey[2] and that of $-.16$ ($p < .05$) between father's level of education and number of mathematics contests entered for the sample of boys in the first wave of the follow-up, all other coefficients (excluding SAT variables as predictors) were less than .15. In the instance of the SAT-M measure as a predictor of number of projects submitted to science fairs, coefficients with absolute values in excess of .20 were found for samples of girls (only) in the first wave of the follow-up ($r = -.37$, $p < .001$) when they were in the seventh or eighth grade, in the second wave of the follow-up ($r = -.22$, $p < .001$) when they were in the seventh or eighth grade, and in the second wave of the follow-up ($r = -.22$, $p < .001$) when they were in the twelfth grade. Relative to the prediction of number of mathematics contests in which students participated from SAT-M scores, correlations in excess of .20 were obtained only for boys: .33 ($p < .001$) and .28 ($p < .001$), respectively, for seventh-and eighth-graders in the second and in the combined third and fourth waves of the follow-up, and .28 ($p < .001$) for twelfth-graders in the second wave of the follow-up. Thus the data suggest that a modest *negative* relationship exists between SAT-M scores and extent of participation in science fairs for girls (but not for boys) and that a modest *positive* relationship occurs between SAT-M scores and amount of involvement in mathematics contests for boys (but not for girls). One could hypothesize that the science fairs may be social occasions for the less able girls and that the mathematics contests are competitive affairs for the more able boys. In any event, attention should be called to the fact that within each of the three talent-search samples at least 80 percent of the students had not submitted a project to a science fair and that in two of the three talent-search samples more than 80 percent of the students had not competed in a mathematics contest. (Obviously, the resulting distribution of responses to the criterion item would be anticipated to contribute to an attenuation in the magnitude of any resulting correlation coefficient with SAT-M scores.)

Substantive and Methodological Limitations

That the findings in the two empirical studies were somewhat conflicting and ambiguous and that the outcomes of the follow-up survey studies were not definitive or conclusive could be attributed to a number of substantive limitations associated with the conceptualization of creativity, to the operational definition of this construct, and to the nature of the learning environment. There were also identifiable methodological difficulties occurring in relation to the unreliability of measures, the restricted range in the ability levels of the subjects within the samples employed, and the violation of assumptions central to the statistical procedures used.

SUBSTANTIVE LIMITATIONS

Among the principal substantive limitations that could have accounted for the somewhat ambiguous and inconsistent outcomes were: (a) inability to conceptualize (to identify or to define psychologically) subconstructs of creativity relevant to problem-solving activities involved in mathematics and science-related tasks, (b) corresponding inappropriateness of the measure (test or scale) chosen to provide a meaningful operational definition or duplication of psychological processes central to creative problem-solving endeavors in mathematics or science, (c) absence of questions in follow-up surveys that were indicative of actual creative behaviors during later years of schooling or during time spent in part-time work or recreation, and (d) failure to provide in the school or home learning environment opportunities as well as reinforcement (rewards) for creative production on the part of the SMPY students. Although one could argue quite convincingly that limitations (b) and (c) were methodological rather than substantive, the conceptualization of creative behavior is so dependent upon and interwoven with its measurement that these two limitations were categorized as substantive.

Need to conceptualize subconstructs underlying creativity in problem-solving in mathematics and the sciences. Although the two empirical studies reported provided interesting information, they appeared to lack a preliminary theoretical framework to afford a direction for research. Somewhat fragmented in nature (as evidenced by the introduction of numerous measures without the presence of a unified rationale for their selection), the rather theoretically barren studies were able to permit only a limited basis for meaningful generalization. Similar comments would also apply to the selection of items incorporated within the questionnaires and follow-up survey forms that were employed. In short, there seemed to be no definition of creative behaviors or products within the context of problem-solving endeavors central to success in mathematics and scientific thinking.

One possible theoretical orientation would be that of the structure-of-intellect (SOI) model (Guilford 1967, pp. 60–66; Guilford & Hoepfner 1971; Guilford & Tenopyr 1968, pp. 26–29) or, preferably, that of the information-processing structure-of-intellect problem-solving (SIPS) model (Guilford & Tenopyr 1968, pp. 30–34). In a recent paper Michael (1977, pp. 156–65) has combined the constructs of the SOI and SIPS models and has related them in a systematic way to Rossman's (1931) seven-step paradigm for invention to furnish what could be at least a partial description of the sequence of steps required for creative production and for problem-solving endeavors in mathematics, science, engineering, and technological invention. This formulation could provide some guidelines for (a) the selection of research questions in future studies that are concerned with the manifestation of creative behavior appropriate to mathematics, science, and engineering curricula, (b) the development of testing instruments and the design of items to be included in follow-up surveys, and (c) the planning of curricular orientations and instructional strategies of relevance to SMPY students.

An alternative theoretical orientation appropriate to study of creative problem solving in mathematics has been developed during the past few years by Sternberg (1977a, 1977b, 1978, 1979, 1980; see also Carroll 1980), who has presented an information-processing methodology involving a componential analysis of tasks leading to use of analogical reasoning. The model is particularly applicable to many kinds of inferential thinking and to syllogistic reasoning. Sternberg's theory of intelligence should have important implications for the understanding of creative production.

Inappropriateness of measures intended to reflect creative behaviors. As so often has occurred in a number of published works about creativity, testing instruments have been chosen, it would seem, by their titles or superficial properties rather than in terms of carefully hypothesized constructs or psychological operations relevant to the problem situation at hand. Such a circumstance may have taken place in the instance of some of the measures used in the two empirical studies that have been reviewed. For example, Kusnitz (1978) made use of Torrance's (1966, 1974) TTCT measures that emphasize divergent thinking primarily in a verbal and figural context of content – abilities that for the most part are not very relevant to creative production in mathematics, but possibly are quite important to tasks in language arts and visual arts. Thus in terms of the formulations of Guilford about problem solving as summarized by Michael (1977, pp. 154–56, 162–65), the creative abilities required in problem solving in mathematics and in the sciences are quite different from those needed by writers and artists.

For instance, whereas creative writers and public speakers are relatively more dependent upon verbal fluency and elaboration (divergent production abilities) than are mathematicians and scientists, mathematicians and scientists often rely quite heavily upon use of convergent production abilities reflecting a flexibility of closure or redefinition of a problem situation or upon cognition, as in being sensitive to new problems or to the implications of their solutions. Evaluation would also be an important component in problem solving in providing a critical judgment concerning the appropriateness of a solution.

Although divergent production may be important to the mathematician in the generation of hypotheses and although memory plays an important part in the retrieval of needed information to cognize a problem situation, *adaptive flexibility* may come closest to reflecting the originality or cleverness of the mathematician or inventor in finding a new solution or a unique solution to a problem encountered in a new context. Thus adaptive flexibility often requires finding new uses of familiar objects or of existing knowledge in ambiguous or foreign contexts to attain a specific goal or unique solution (convergent response), and the *sensitivity to problems* frequently demands an awareness (cognition) of implications, difficulties, and risks that one is likely to encounter in undertaking a new assignment or in solving a problem – risks that need to be evaluated along with the promise and correctness of any solution proposed. In short, it would appear that most measures of creative production employed in the context of problem-solving endeavors by gifted students in the areas of mathematics and science have not been addressed to these complex components of the problem-solving process.

Absence of relevant questions in follow-up surveys. One of the most likely reasons for lack of realization of correlation between antecedent variables in a talent-search questionnaire and the criterion items in the follow-up survey forms is the failure to ask the appropriate or relevant question indicative of creative behaviors in mathematics and in science-related activities in the school setting. Of course it is possible that the inclusion of relevant questions in the survey form still would have resulted in a lack of significant correlations with the antecedent variables because of the actual lack of relationship of background variables to subsequent creative behaviors.

Failure to provide in the learning environment opportunities and rewards for creative endeavor. It is not known precisely the extent to which opportunities were present for students to take part in science fairs and in competitive contests in mathematics. Hence, some degree of attenuation in correlation coefficients might have occurred for lack of availability of experiences challenging the students' creative potentialities. Even if relevant questions about creative endeavors had been posed in follow-up surveys, significant correlations with antecedent variables might not have been attained because many a teacher – even one of gifted children – fails to offer a learning environment in which students can be given unique, unusual, or challenging problems within the classroom setting or can be rewarded for creative problem solving that can be initiated either within or outside of school. Many a teacher is likely to be threatened or inconvenienced by any change in the status quo of the classroom setting or of the curriculum. Clearly, unless a teacher is prepared to individualize instruction, the mathematically gifted child may become frustrated and hence lost to society as a potentially creative contributor. Information regarding how teaching for creative endeavor may be achieved was set forth in detail by Michael (1968, pp. 237–60; 1977, pp. 165–68).

METHODOLOGICAL LIMITATIONS

Several procedural and methodological shortcomings undoubtedly contributed to the realization of only a small degree of relationship between pairs of variables studied. Unfortunately, the extent to which practical remedial steps can be taken is often far short of what would be desired.

Unreliability of measures. Partly because of the restriction in range of talent, the potential reliability of measures employed in the two empirical studies was probably quite attentuated. Furthermore, reliability of scoring the TTCT was questioned. Responses to single items in the questionnaire and survey forms employed by SMPY could be expected to be comparatively unreliable. Combining items into clusters to enhance the reliability of resulting composites did not seem to be appropriate in most instances because of the lack of homogeneity in the items.

The extent to which lack of uniformity in conditions underlying administration of tests, questionnaires, and survey forms or lack of accuracy in the scoring and recording of data might have contributed to unreliability cannot be determined. Another interesting concern would rest upon the possible facilitating or inhibiting effect of the use of the word *creativity* in a number of measures employed.

Restriction of range. In addition to its effect upon the reliability of the criterion and antecedent measures obtained, restriction of range would contribute concomitantly to a reduction to the coefficient of correlation between any two measures. No attempt was made to correct coefficients for restriction of range, as it was difficult to specify any rules of explicit or implicit selection. Thus one should realize that the marked reduction in range of talent probably militated substantially against obtaining higher indexes of relationship between variables.

Violation of statistical assumptions in data analyses. That several of the distributions of responses to items with ordered alternatives were truncated or skewed probably resulted in the inappropriate use of the Pearson product-moment correlation coefficient relative to the analysis of data in the follow-up studies of students. As curvilinearity was probably often present in many pairs of variables, the correlation estimates were very possibly lower than would have been the corresponding eta values. It must be noted, however, that if two variables being correlated have quite different distribution shapes, they cannot correlate even close to the usual -1.00 and 1.00 limits. Not unless every examinee has the same z-score on the X variable as he or she has on the Y variable can Pearson *r*'s have the unit limits. Obviously, in the instance of the two empirical studies reviewed, no immediate determination of possible curvilinearity could be made.

Recommendations

On the basis of this critique, several recommendations are offered in carrying out future investigations that might contribute to the realization of an improved or more nearly accurate answer to the question posed at the beginning of the paper:

1. At the time of selection of future SMPY students, supplementary measures reflecting the creative abilities required in successful problem solving in mathematics and in the sciences (as determined from theoretical considerations and the results of empirical studies) should accompany use of the SAT-M to provide evidence of the nature and the degree of the relationship between creativity and general intelligence. In addition, these

measures could be used as a basis for selection, placement, and counseling of students.

2. Alternate forms of these same measures could be administered to students just prior to their college entrance to examine gains in scores on each of the measures and to ascertain whether a change in degree of relationship between creativity and intelligence has occurred. (It is of interest to note that in the current study mean SAT-M scores for samples of boys in the first, second, and the combined third and fourth waves of the follow-up surveys while they were in the seventh or eighth grade were 567, 549, and 526, respectively; four to five years later the respective means were 691, 693, and 695. In the instance of girls the corresponding mean scores while they were in the seventh or eighth grade were 505, 510, and 498; four to five years later, 652, 643, and 650.)

3. It is urged that affective measures such as those pertaining to locus of control and field independence (constructs based upon extensive theoretical conceptualization and empirical research) also be administered to determine whether any moderating effects could be identified and whether subsequent prediction of college success could be enhanced.

4. In a manner somewhat parallel to that followed by Terman and Oden (1959) and Oden (1968) long-term longitudinal studies should be initiated for all participants in recent and in future SMPY groups to obtain evidence of tangible creative contributions to mathematics, science, engineering, business, industry, and health professions in terms of products such as published papers, books, awards, honors, patents, and other original or innovative works. If possible, the use of comparison or control groups of individuals with somewhat modest levels of mathematical ability should be employed to obtain evidence of differential rates of productivity, both in quality and in quantity.

5. In future studies parallel to those just described efforts should be made to follow males and females as separate groups to learn whether women with requisite qualifications comparable to those of men achieve at an essentially equivalent level, or are possibly inhibited by societal restraints.

Concluding Statement

The Study of Mathematically Precocious Youth has made significant contributions to the identification of highly talented youth in mathematics and has substantially facilitated their progress in the educational system. It is incumbent upon the professional members of SMPY to monitor the attainments of this truly exceptional group to ensure to the maximum degree possible the fruition of their creative potentialities. From the information gained through frequent communication with these gifted individuals during the next several years modifications can be made in educational programs that will probably lead to increasingly significant creative attainments on the part of members of newly selected groups.

Notes

1. Because the TTCT was not scored by the staff of SMPY, Kusnitz had no control over the reliability and quality of scoring of this test.

2. The follow-up of the students in the first three talent searches was conducted in four waves so as to have the questionnaire reach the student in the fall after high-school graduation (see Benbow, chapter 2 of this volume).

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